Schulz and Marble

Investigation of Induction Machines

Electrical Engineering

E. E.

1900

THEORETICAL AND EXPERIMENTAL INVESTIGATION OF INDUCTION MACHINES

BY

WILLIAM FREDERICK SCHULZ,

DIPLOMA IN ELECTRICAL ENGINEERING (JOHNS HOPKINS UNIVERSITY), '93

AND

HARRY CURTISS MARBLE, B.S., '96

THESIS

FOR THE DEGREE OF ELECTRICAL ENGINEER

IN THE GRADUATE SCHOOL

UNIVERSITY OF ILLINOIS

1900

UNIVERSITY OF ILLINOIS

June 1, 1900

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

William Frederick Schulz and Harry Curtiss Marble

ENTITLED Theoretical and Experimental Investigation of Induction Machines -

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Electrical Engineer

Wm. A. Aldrich.

HEAD OF DEPARTMENT OF Electrical Engineering

P R E F A C E.

The work on this thesis was undertaken with the collaboration of Mr. Harry C. Marble, B.S., Assistant in Electrical Engineering, and a post graduate student in the Department of Electrical Engineering of this university.

In treating the theory of induction motors, the method developed in the well known book on "Alternating Current Phenomena" by Mr. Chas. P. Steinmetz, has been followed.

Through the courtesy of the Wagner Electric Manufacuring Company, of StLouis, Mo., we were supplied with a 4 h.p. and a 7 ½ h.p. motor on a special loan to the University of Illinois, for this investigation. Also, we visited the works of this Company May 17th and 18th, and there made a regular factory test of a 10 h. p. motor, using their methods and the University of Illinois instruments connected up with the regular shop testing instruments of this company.

TABLE OF CONTENTS.

DISCUSSION OF CURVES

PLATES

T H E O R E T I C A L & E X P E R I M E N T A L I N V E S T I G A T I O N O F I N D U C T I O N M A C H I N E S.

In writing this thesis the author has had a twofold purpose in view, as indicated by the title. The object object has been to test by brake the output of single phase induction motors, which combined with electrical measurements and the electrical and mechanical data of the machines, determines the true and apparent efficiency, power factor, idle watts, torque, slip, etc. Moreover it was expected that the calculated results from theoretical considerations would afford an interesting comparison with those experimentally determined, but owing to the difficulties encountered in determining the proper values of the reactances of rotor and stator and the magnetic flux, these calculations could not be made.

Before discussing the experimental results it may not be out of place to explain the principle of an induction motor, such as one of the short-circuited-armature type.

The stator or fixed part consists of an annular field of laminated iron having wire coils wound in slots and arranged to form as many poles as it is desired the machine should have. The rotor or rotating part consists of a cylinder of laminated

consists of a cylinder of laminated iron, mounted on a shaft, having also slots in which are imbedded either wire coils or copper bars, all of which are short-circuited on themselves by a copper or brass ring, or other device.

The alternating current is supplied to the stator, establishing in it a rotary field of force. This field is cut by the conductors of the rotor, inducing in them an E. M. F. which though small is sufficient to set up a large current in the rotor winding. The reaction of the field of force induced in the rotor, on the rotary field of the stator causes the rotor of the single phase machine to continue to revolve if once set in motion.

The frequency of the stator rotary field is equal to the frequency of the impressed E. M. F. The revolutions per second of the rotary field are equal to the E. M. F. divided by the number of pairs of poles of the stator. The frequency of the rotor current is the same as this when the rotor is at standstill, but decreases as the rotor speed increases becoming zero at synchronism. Hence the frequency of the rotor E. M. F. varies directly with the slip, and the number of revolutions at any slip is

$$(1-S)\,N$$

where N = frequency of stator

S = percentage slip

SN = frequency of rotor.

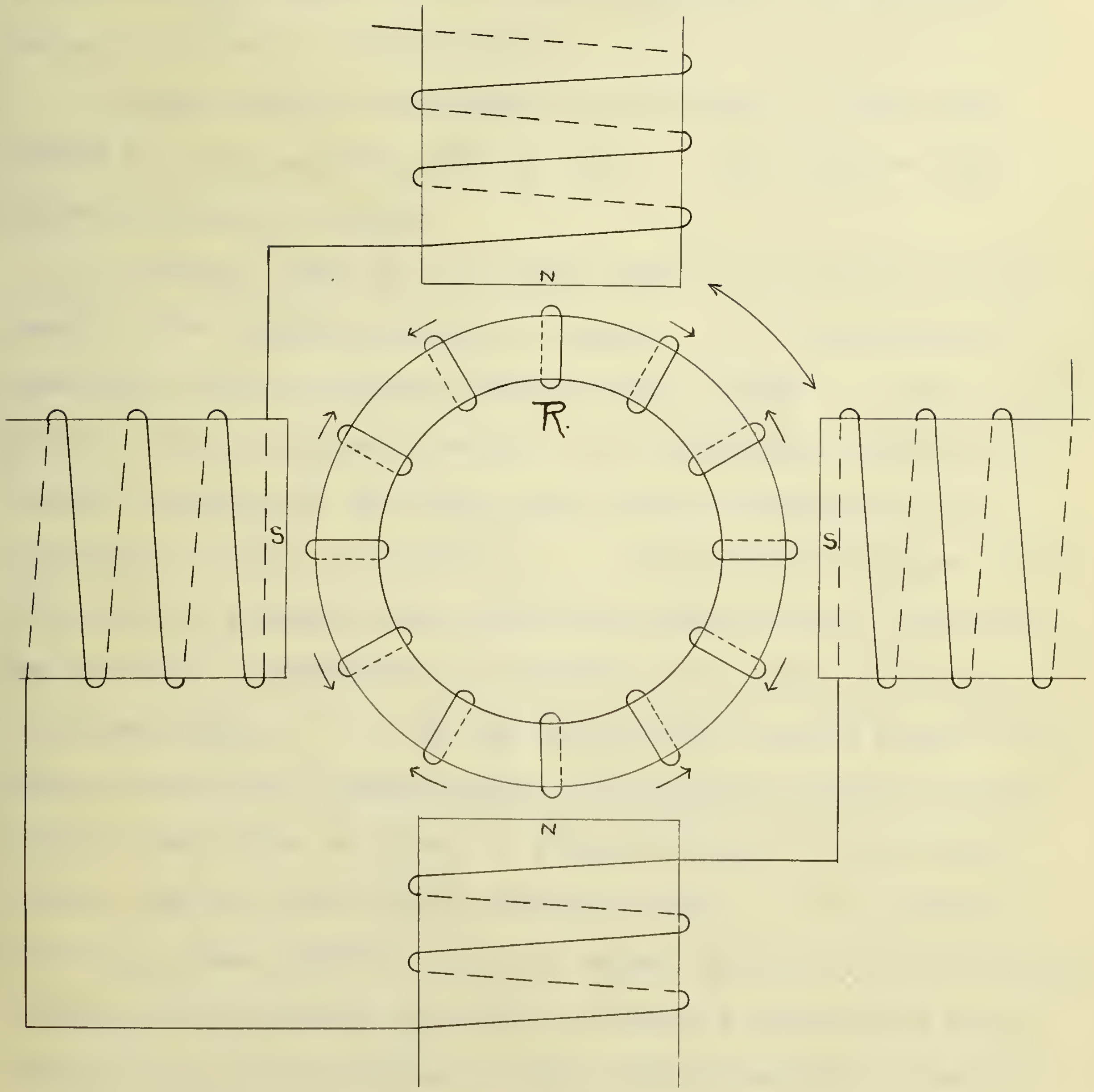
The stator and rotor are sometimes referred to as the primary and secondary of the motor since they bear to each other the same relation as these parts of a transformer having one of its circuits movable. When the rotor is at standstill it is considered as a short-circuited transformer secondary.

In polyphase induction motors the field produced by the stator windings is rotating, and the rotor will start of itself. In the single phase motor the field is not a true rotating field until the rotor has gotten up to considerable speed, when the resultant of its field and the field of the stator becomes a true rotating field or approximately so in effect, and the motor will therefore keep in motion.

If the rotor is at standstill and is wound with uniformly spaced short circuited coils or bars, the repulsive thrust between induced current and inducing magnetism, in the different coils, will balance each other and there will be no tendency for the rotor to revolve, as is shown in diagram Fig. 1. Here for each coil receiving a rotary thrust in one direction, there is a symmetrically placed coil on the opposite side of the rotor R, receiving an equal thrust in the opposite direction.

To overcome this effect several means are employed, one of these being the "phase splitting" method which consists of a field winding similar to that of a two phase machine. One of the coils contains an inductance, and the other a different inductance or a capacity.

Fig. 1.

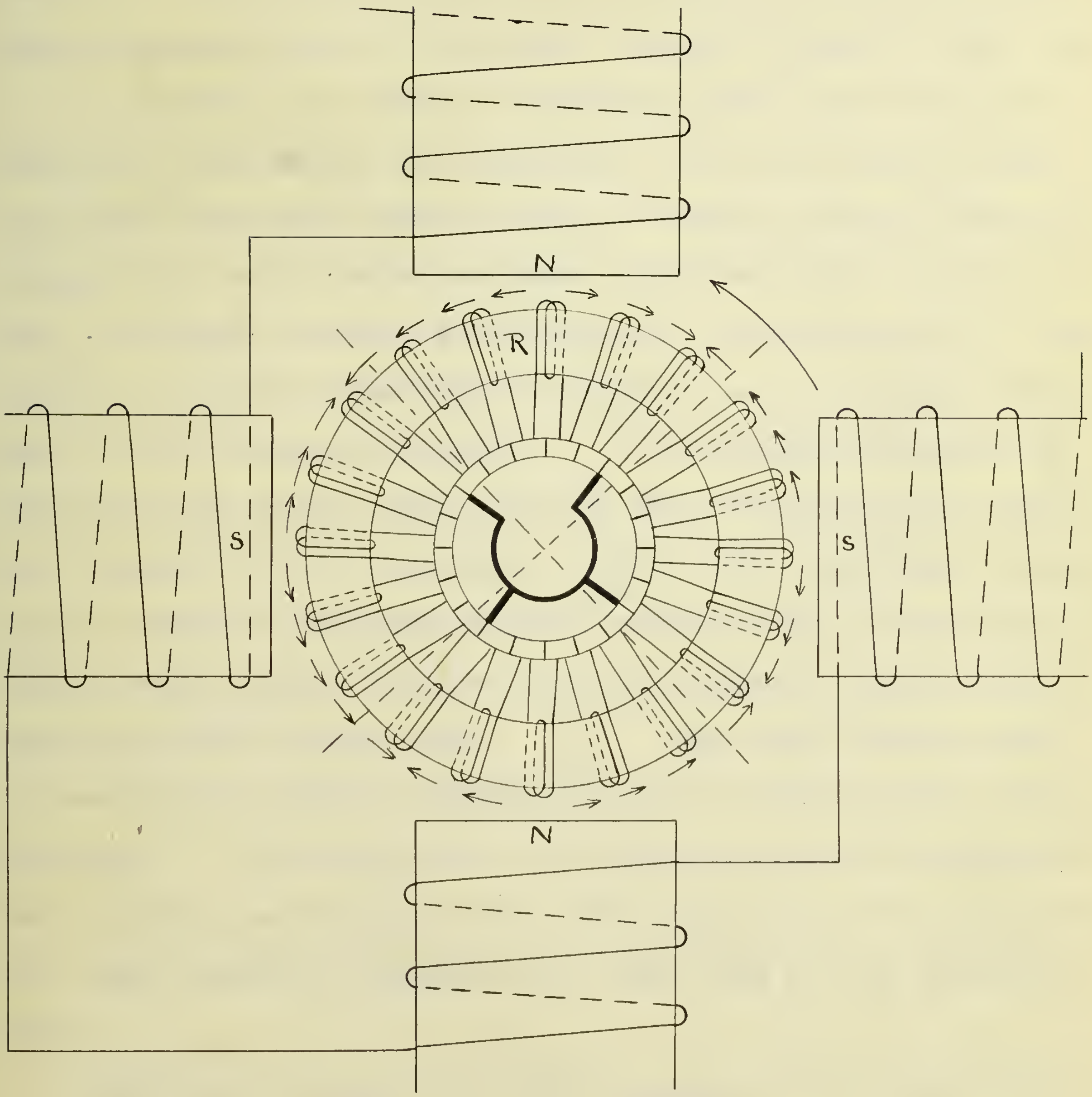


Both coils are connected in parrallel in starting, thus causing a difference of phase of the field magnetism, the resultant being, in effect, a rotary field.

In some motors a commutator is used and the rotor and stator are put in series in starting. The machine then starts as a series motor.

In others, such as the Wagner Motors upon which we experimented, the repulsion method is used. In these motors a commutator having vertical radial bars is used. The winding of the rotor is the same as that of a continuous-wound direct current armature of four pole type, and is connected to the commutator in the same manner. Four carbon brushes, short circuited by a heavy brass connection, bear on this commutator. The armature is therefore equivalent to one having four short circuited coils. If the brushes were placed symmetrically midway between the stator poles, the repulsive thrusts would balance each other as shown in diagram Fig.1, by the small arrows, and the rotor would remain at rest. If, however, the brushes are shifted from this midway position, the repulsive thrusts are unbalanced as shown in figure 2 (where the small arrows at the circumference of the rotor R show the direction of the repulsive thrust) and the rotor will tend to rotate in the direction in which the brushes were shifted. The speed of rotation increases until it is almost at synchronism, when the brushes are thrown back from the commutator and a ring of

Fig. 2.



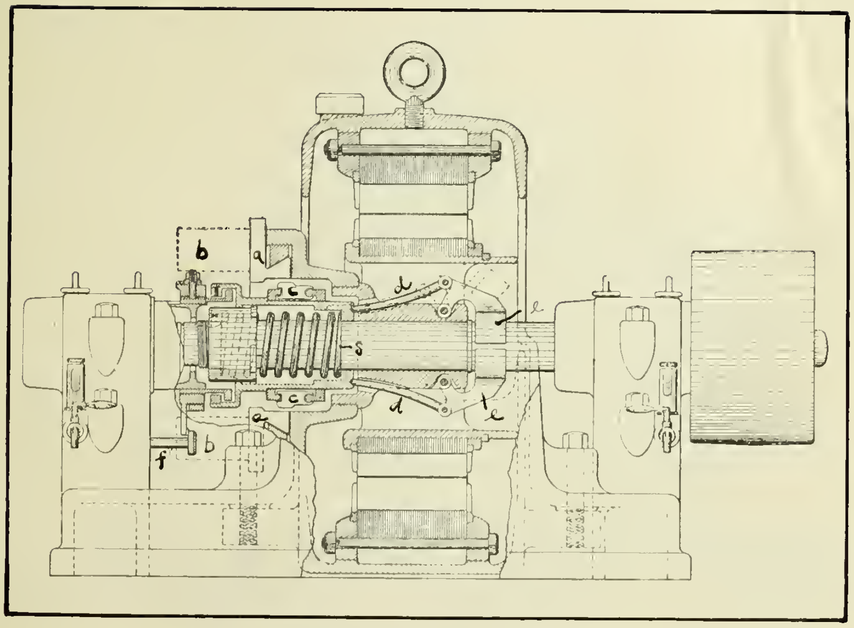
copper links is forced up against it, thus short circuiting all of the rotor coils. As the field at this speed is approximately a rotary field, the motor now operates just as a polyphase induction motor of the short circuited armature type does.

In Fig. 3 is shown a sectional view of the motor, in which (aa) represents the commutator, (bb) the brushes which are short circuited, (cc) the ring of copper links by means of whichall the rotor coils are short circuited, (dd) the arms of the centrifugal governor which controls the throwing off of the brushes and short circuiting of the rotor at the proper speed, and (ee) the governor weights. The synchronous speed of the four pole, sixty cycle motor is 1800 revolutions per minute The governor is set to operate at about 165o revolutions, allowing the motor to be operated when the frequency is less than sixty cycles, as for instance when the generator speed drops somewhat under a heavy load. When this latter speed is reached the governor weights fly out as shown in the dotted position. By this action the spiral spring (S) is compressed, drawing the brushes back by the spring knob (f) and forcing the copper links (cc) against the inner ends of the commutator bars.

The motors tested were of the standard, two, four, seven and a half, and ten horse-power sizes, respectively.

There are four brushes placed 90° apart, except in the two horse-power size, in which there are but two brushes, placed 90° apart. The reason assigned for this is,

— Fig 3. —



Longitudinal Cross Section of Motor.

that larger sizes carrying more current require larger brushes; and that the four brushes mechanically balance to better advantage on the brush carrying ring.

In the blue prints, Figures #4, 5 and 6, are shown sections of the laminae, of which the rotor and stator cores are built up respectively.

The slots on the rotor are not parallel to the axis of the shaft but are arranged spirally. This brings them into and out of the field of the stator gradually and thus reduces the humming which would otherwise occur. The number of commutator bars is not an even multiple of the number of slots on the rotor. For instance, in the two horse power machine which has a two-circuit, double-layer, drum-wound rotor, there are forty seven slots, but only ninety three commutator bars. In such a winding with a stator having an even number of pairs of poles, there must be an uneven number of coils. There are thus ninety three active coils or 186 conductors. However, in order to wind the rotor symmetrically, with four conductors per slot, the number of conductors should be an even multiple of four. Hence there are 186 + 2 = 188 conductors or ninety four coils, and forty-seven slots. The extra coil is left open-circuited, and is used only to balance the armature.

These machines also have a special device for starting under full load or even as much as 75% overload. This is accomplished by bringing out a third terminal forming a

that larger slots carrying more current [illegible],
and that the rotor becomes mechanically balanced to [illegible]-
ings on the brush carrying rings.

In the blue prints, Figures 4, 5 and 6, are shown sec-
tions of the laminae, of which the rotor and stator cores are
built up respectively.

The slots on the rotor are not parallel to the axis of
the shaft but are arranged spirally. This brings them [illegible]
and out of the field of the stator gradually and thus reduces
the humming which would otherwise occur. The number of
commutator bars is not an even multiple of the number of [illegible]
on the rotor. For instance, in the two horse power machine
which has a two circuit double layer, drum wound rotor, there
are forty seven slots, but only ninety three commutator bars.
In such a winding with a stator having an even number of pairs
of poles, there must be an uneven number of coils. There
are thus ninety three active coils or 186 conductors. However,
in order to wind the rotor symmetrically, with four conductors
per slot, the number of conductors should be an even multiple
of four. Hence there are 188 [illegible] 188 conductors or
ninety four coils and forty-seven slots. The extra coil
is left open-circuited, and is used only to balance the [illegible]

These machines also have a special device for starting
under full load or even as much as 75% overload. This
is accomplished by arranging for a third terminal [illegible] a

—Fig 4.—

Rotor & Stator Stampings for

2 & 4 H.P. Motors.

Fig 5.

Rotor & Stator Stampings for

5, $7\frac{1}{2}$ & 10 H.P. Motors.

Fig 6.

Rotor & Stator Stampings for 15 H.P. Motor.

so-called"loop" to the stator winding.

Under normal starting and running conditions, the double pole switch in Fig. 7c is down, the single pole up. This is diagrammatically shown in Fig. #8. When both switches are down, connecting one line wire to this third terminal, the effect is the same as cutting out some of the field windings and a larger current flows through the remaining ones. The maximum starting torque is then developed. Fig. #9 shows this connection diagrammatically. When it is desired to cut down this excess of current a small so-called "auto-transformer" is used as shown in Fig. #7c, by which arrangement the impressed voltage is reduced. Fig. #10 is a diagram representing this condition.

The motor is started with both switches up, and after the acceleration of the rotor has ceased, the single pole switch is thrown into the"loop" position. After further acceleration has ceased, the double pole switch is thrown down into running position and the single pole up or outside the loop, which is the position for normal running.

In Fig. #13 is shown a diagram of the winding on the stator, and the loop connection,for a four-pole, one-hundred & four volt machine. The "loop" terminal is marked "B" and the windings cut out by this connection are marked 1a, 2a, 3a and 4a. The two pairs of poles are connected in parallel.

Fig 7.

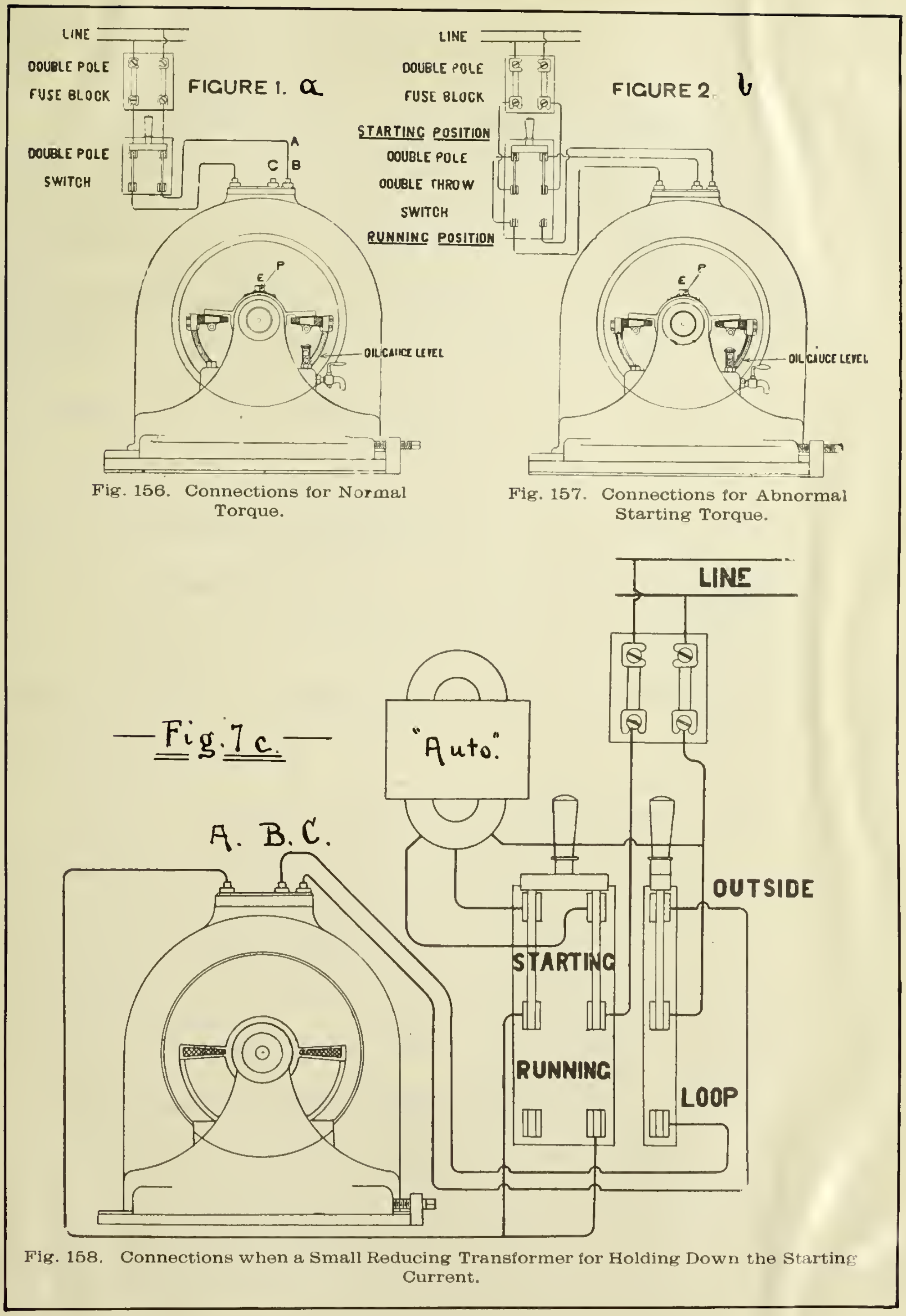


Fig. 156. Connections for Normal Torque.

Fig. 157. Connections for Abnormal Starting Torque.

Fig. 158. Connections when a Small Reducing Transformer for Holding Down the Starting Current.

Fig. 13.

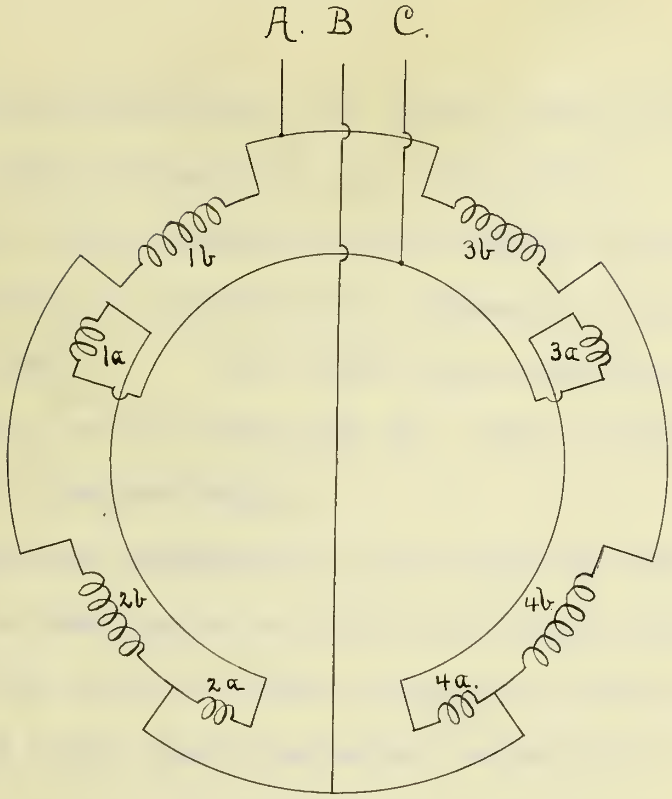
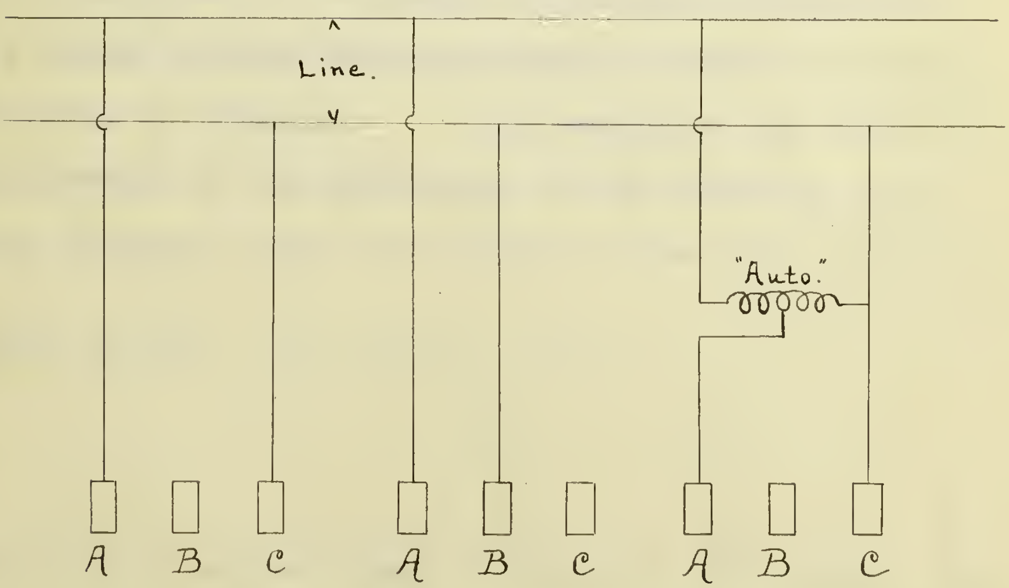


Fig. 8. Fig. 9. Fig. 10.



The windings constituting the stator poles are in the shape of flat coils threaded through the slots. This produces maximum field strength in the middle tooth of the pole, the intensity of magnetisation gradually diminishing toward either side. The coils are connected in parallel, or in series, as the case may be, for a terminal voltage of 104 or 208 respectively.

The machines are designed to run on 110 or 220 volt circuits, but are designated as 104 or 208 volt motors.

In making the tests of these motors the Prony-brake was used. The brake wheel was water cooled and of the form of cross section shown in Fig.#11, the radius being six inches. Hence in the tables, the torque in foot pounds is obtained by dividing the pull in pounds by two.

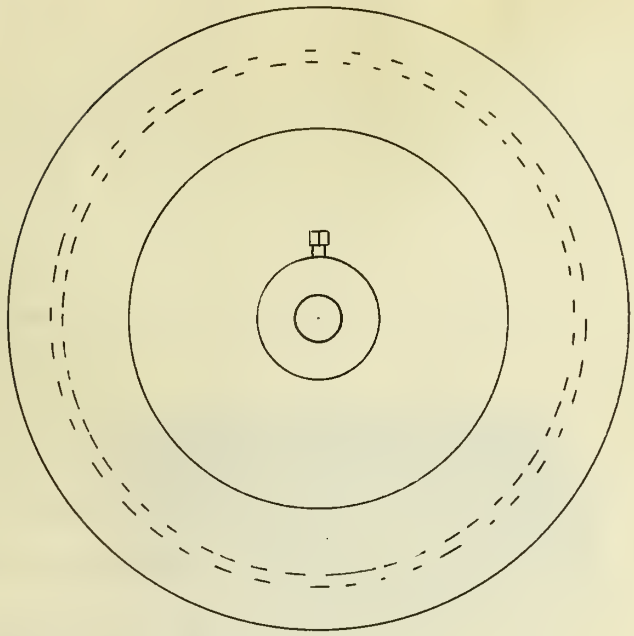
A spring balance was suspended above the wheel and a rope which hung from it, encircled the wheel and supported below the latter another spring balance in order to measure the difference of tension. The actual or net pull on the circumference is the difference of the readings of the two spring balances, minus the weight of the lower balance; or,

$$\text{pull in lbs} = \left[T_1 - (T_2 + Wt\ )\right]$$

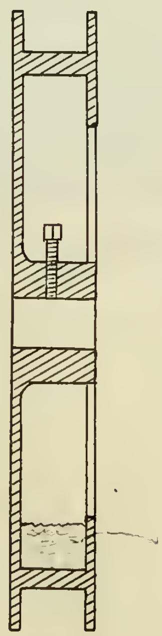
The speed at any time was taken as equal to the speed of the

Fig. 11.

Elevation

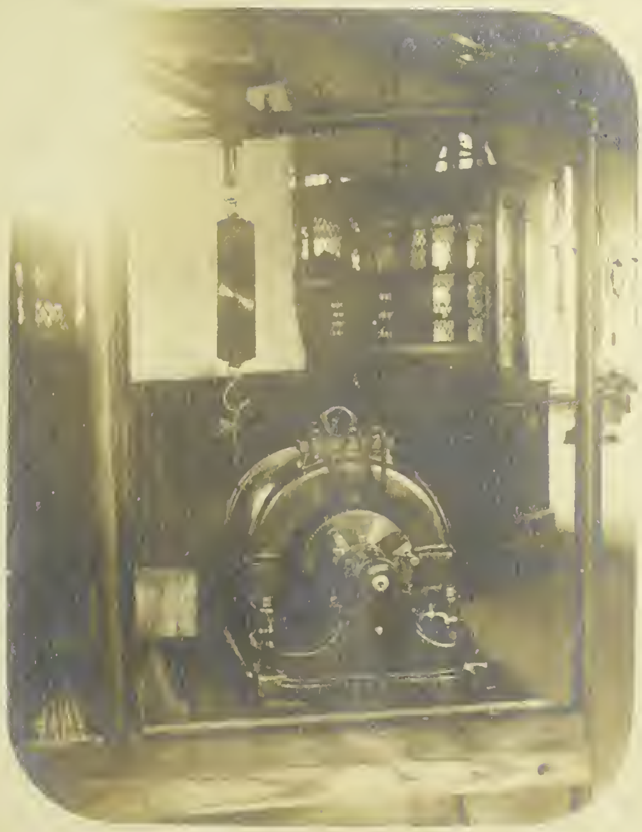


Brake Wheel



Section

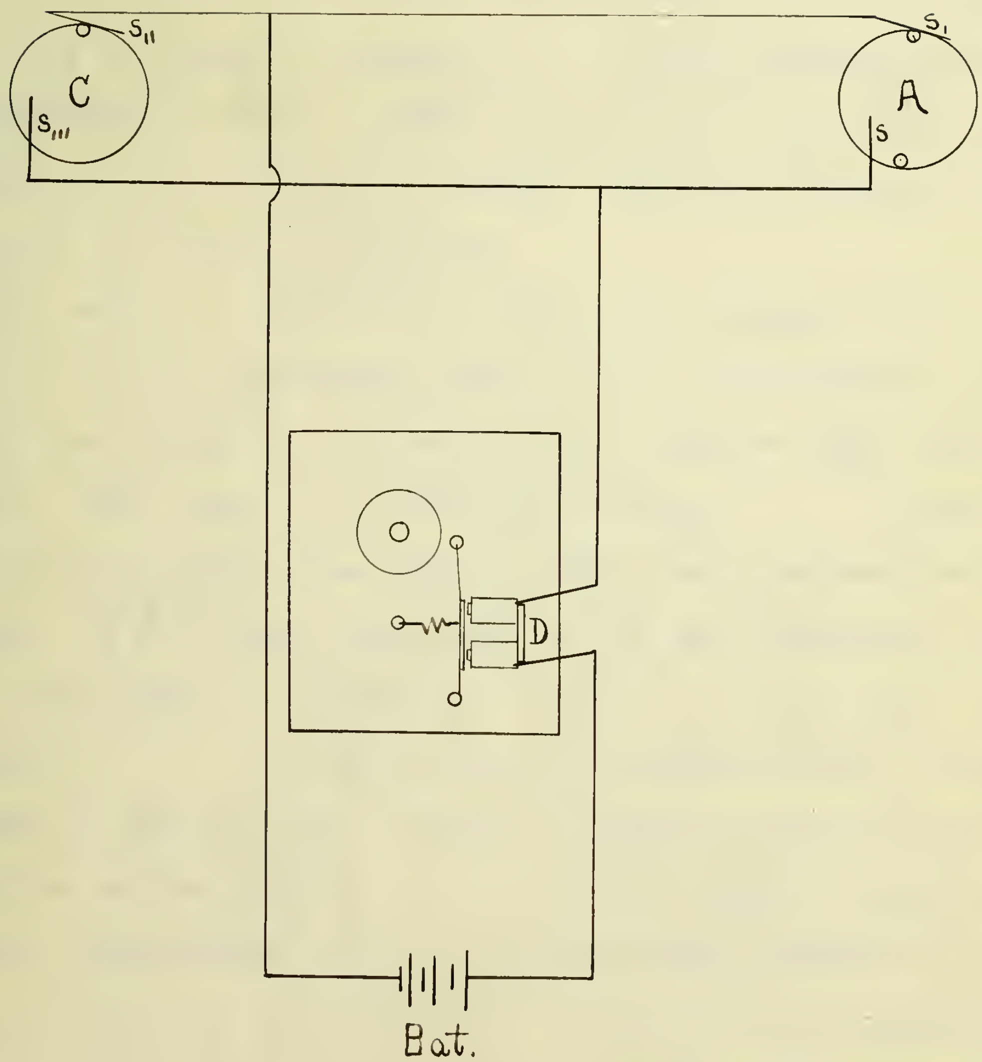
Water



generator minus the slip of the rotor, expressed in revolutions per minute, since both generator and motor had the same number of poles. The method of determining the slip by use of the contact breaker was as follows;

In Fig. #12, A represents a small synchronous motor which was run from the same generator as the induction motor C On the shaft of the synchronous motor was mounted a small brass wheel on which springs S and S_1 bear; S makes contact all the time, while the contact of S_1 is broken twice at each revolution of the wheel by means of two pieces of glass set in its circumference. On the induction motor was placed a similar breaker, having, however, only one contact break since the number of poles (4) of the induction motor was one half the number of poles of the synchronous motors. These two pairs of springs were placed in parallel and a current from a storage battery B. was passed through them in series with the single stroke electric bell D. The armature of the bell was pulled up by its magnets and held while there was current through the magnet coils. By this arrangement the bell would ring by the action of the opposing spring, whenever the circuit was broken simultaneously on both contact wheels. This method of using a closed circuit electric bell with the two contact breakers in parallel was adopted after trying many other devices. When two contact "makers" were used in series, the time of "make" was found to be so small, that the self

Fig. 12.



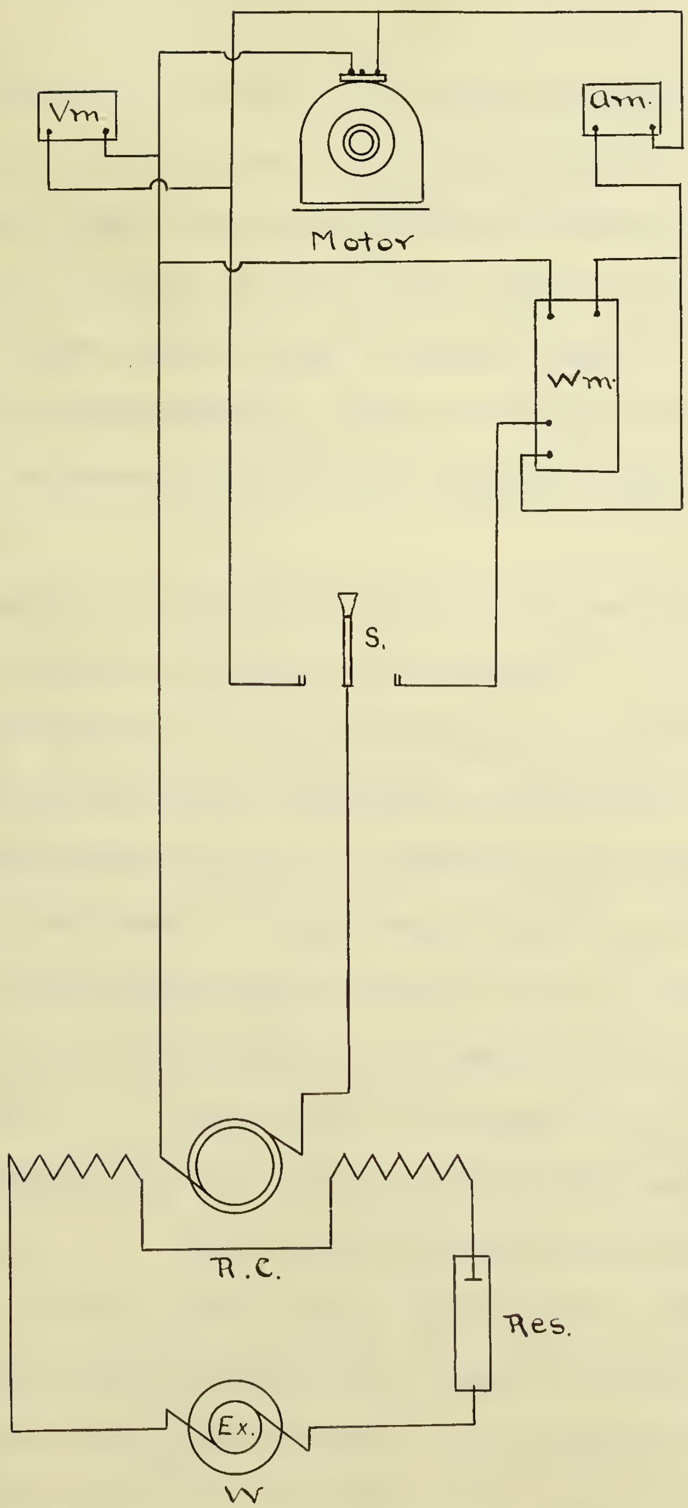
induction of the bell coils would not permit of establishing sufficient current to pull the bell armature over to the magnet during the interval of contact. This interval, however, was sufficiently long to permit the spring to pull the armature away at the instant of "break" - when two contact breakers were used, connected in parallel.

The action in detail was as follows; suppose both $S_{\prime}$ and $S_{\prime\prime}$ to be on the insulating points of the two contact break wheels; the spring is then holding the armature away from the magnets, since there is no electric circuit. If the break wheels revolve, the springs will touch the brass, making contact, and the magnet will pull up the bell armature, holding it until the breaks in A and C, occur again simultaneously. At such instant the magnet again releases its hold of the armature, causing the bell to ring, through the action of the spring. If the induction machine revolves with exactly twice the speed of the synchronous motor, the bell will ring once for each revolution of the induction motor or twice for each revolution of the synchronous motor. However, when a load is put on the induction machine, its speed will drop to a smaller constant value, depending upon the load If it loses one complete revolution the breaks in A and C will occur again simultaneously, and the bell will ring.

This interval represents one revolution of slip. Counting the time for a certain number of such intervals or of rings, gives the slip in actual revolutions per minute, from which the percentage slip is obtained. Each motor was tested at 75, 9o, 1o4 and 12o volts, the voltage being kept constant under all loads, in each test. The instruments for testing were connected as shown in diagram Fig. 14. M represents the induction motor receiving current from the 7-½ K.W., G.E. rotary converter R.C. The fields of the latter were excited by the 3 K.W. Weston machine and the voltage regulated by means of the water rheostat, Res. Wm represents the Weston wattmeter. Am the Thomson ammeter and Vm the Weston voltmeter. S represents a single pole, double throw switch, by means of which the instruments were cut out of circuit on starting to avoid the heavy rush of current. The motor was loaded gradually by increasing the tension on the brake rope, and readings taken at different loads. The voltage was kept constant by regulating the excitation of the rotary converter by means of the water rheostat.

The values observed were volts at the terminals of motor (constant) amperes, true watts input, pull in pounds on the circumference of the brake wheel, and slip in revoltations per minute. From these values were calculated the brake horse-power output, the apparent watts input, true efficiency,

Fig. 14.



apparent efficiency, power factor, idle watts, and percent slip.

To compare the results, the values ontained were plotted in a full set of curves on a "percent of full load" base.

To obtain some data and information about the motors, we visited the factory of the Wagner Electric Manufacturing Company and there made a test on a 2o8 volt, 10 H.P. induction motor by their method, using the University of Illinois instruments connected up with the regular shop testing instruments.

The essential difference between the shop method of testing and our own is in loading the motors. In the shop the motor is belted to a separately excited direct current generator, which has been carefully calibrated, and curves of motor horse-power output at different generator plotted. The motor is run from a transformer, and the voltage at the terminals of the former is adjusted to 1o4 or 2o8 volts as the case may be, by cutting out primary or secondary turns of the latter. Each motor is tested at no load, half - full -and maximum load, on both the"outside" and the "loop" connections. The desired load is put on the generator and readings of the motor volts, amperes and watts input are taken. The "slip" at different loads is not observed. The agreement of the instruments of the Wagner Co. with those which we took with us can be seen from table

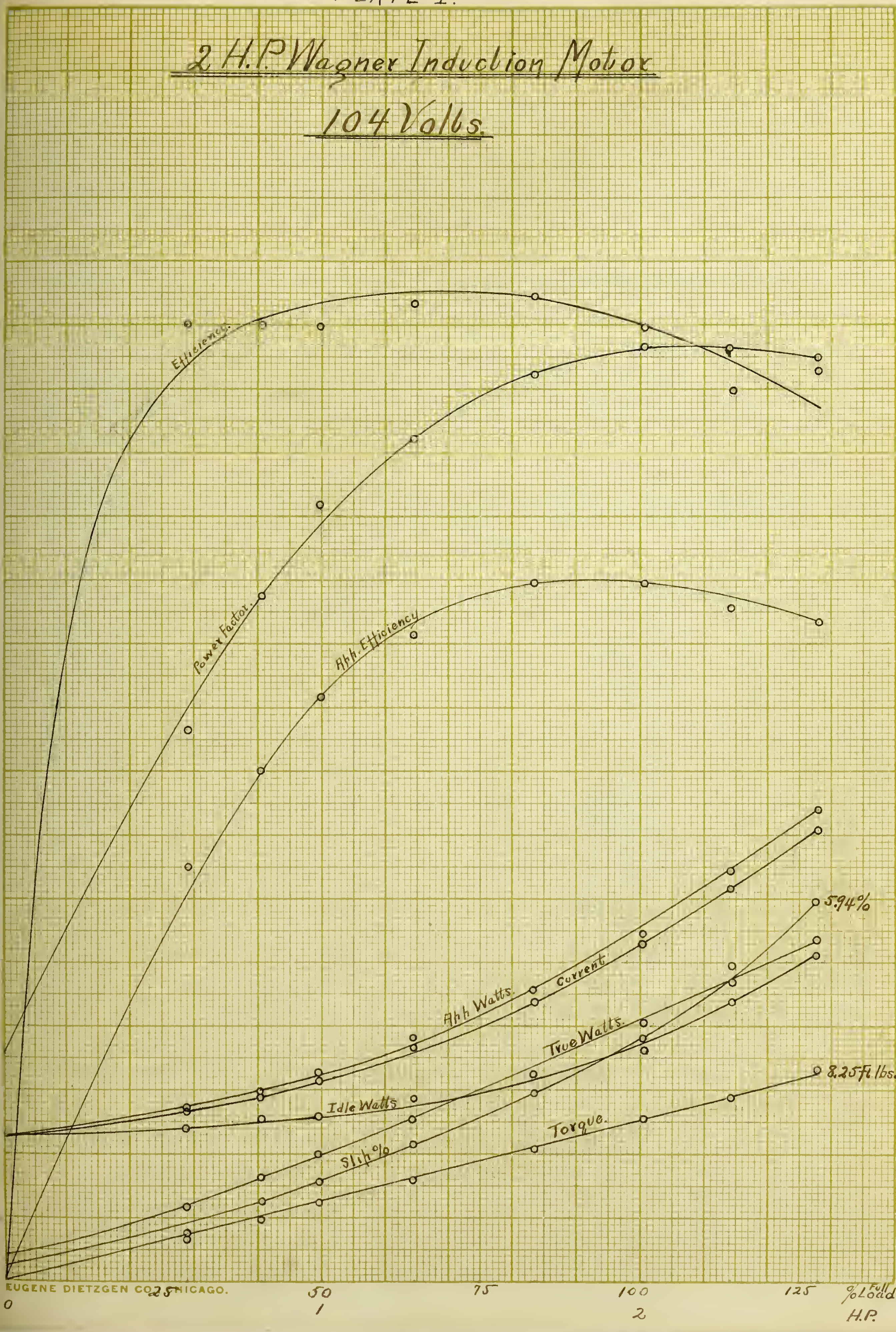
In Plate I the entire set of curves for the 2 H.P.motor at nominal voltage (104) are plotted. The efficiency curve is highest at about 75% of full load, reaching a value of 77.2 and bends down at full load decreasing as the machine is overloaded. The idle watts increase nearly in a straight line to 75% load and then rise more quickly until a value of 2540 watts is reached at full load. The maximum power factor occurs at about full load and decreases slightly at more than 100% of load, corresponding to the increase of idle watts.

In this discussion we mean by "idle watts" not the no load watts, but the product of the apparent watts or volt-amperes, by the sine of the angle of lag.

The maximum torque is 8.25 foot pounds and the torque curve is of course a straight line when plotted on a horse power or % load base

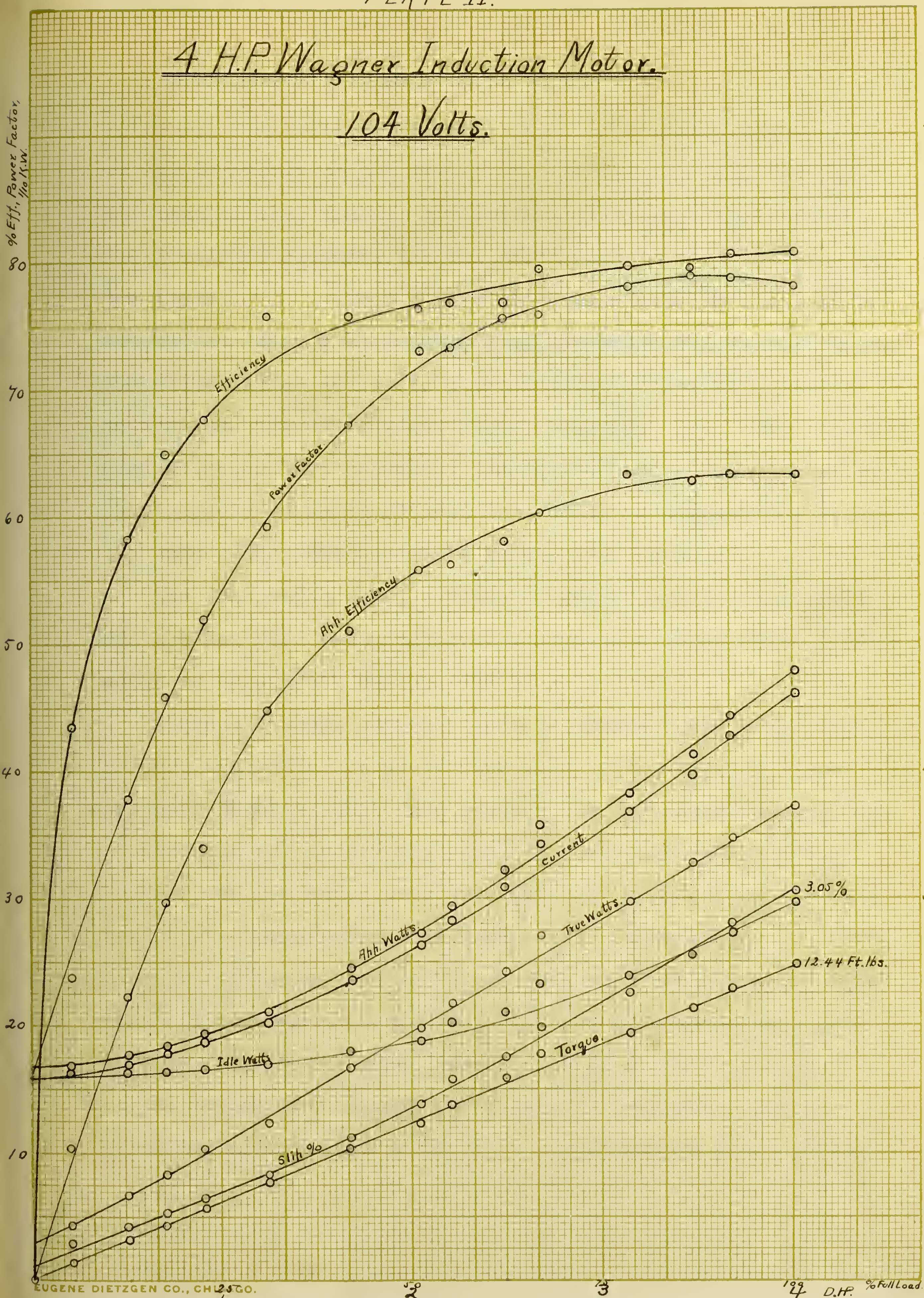
In Plate II corresponding curves for the 4 H.P. motor are plotted. In this motor the efficiency had not reached a maximum at full load, at which point its value was 80.5% The power factor reaches a value of 79% at 87-1/5% of full load The maximum torque is 12.44 ft lbs. and on attempting to go beyond this the motor fell "out of step" These tests were all run from the rotary converter of 7.5 K.W. capacity and it would certainly seem that if the motor could carry an excess of rated load that a 7.5 K.W. generator would be sufficient

PLATE I.



2 H.P. Wagner Induction Motor
104 Volts.
% Eff. Power Factor
1/10 K.W.
Efficiency.
Power Factor.
App. Efficiency
App. Watts.
Current
True Watts.
Idle Watts
Slip %
Torque.
5.94%
8.25 Ft lbs.
80
70
60
50
40
30
20
10
0
25
50
75
100
125
% Full Load
1
2
H.P.
EUGENE DIETZGEN CO. CHICAGO.

PLATE II.


4 H.P. Wagner Induction Motor.
104 Volts.
% Eff. Power Factor, 1/10 K.W.
% Eff. Power Factor 1/10 K.W.
80
70
60
50
40
30
20
10
Efficiency
Power Factor
App. Efficiency
Current
App. Watts
True Watts.
Idle Watts
Torque
Slip %
3.05%
12.44 Ft. lbs.
EUGENE DIETZGEN CO., CHICAGO.
25
1
50
2
75
3
100
4
D.H.P.
% Full Load

to supply the necessary power. We stated this case to the engineers of the Wagner Co., adding that the voltage was held at 1o4, and the explanation given was, that either the generator capacity was not sufficient or that our line was too small. They stated also that they had had similar trouble at times when running from a static transformer, being compelled either to put in a transformer of larger output or to wind the transformer for higher voltage. The statement of the rotary converter and line capacity being insufficient hardly seems to fit the case since we transmitted under the same conditions 5.88 H.P. to the 7-½ H.P.motor.

The idle watts reach a value of 2960 on this 4 H.P. motor and are far from being constant rising in a curve whose bend seems to be between 50% and 75% of full load.

Plate 111 shows curves of the 7-½ horse power motor though we were unable to run above 5.88 H.P. Insufficient line capacity might in this case account for the motor falling out of step but the true watts supplied were only 5445 and the E. M. F. at the motor terminals was kept constant so it would seem that a higher output should have been obtained. The maximum efficiency was 8o.7% occuring at 6 horse power. The power factor was high reaching 87%; the idle watts were only 3070 and though the curve seemed to rise at half load the values beyond that seemed to be less in proportion so the curve was constructed as shown. The maximum slip is 2.82%

PLATE III.

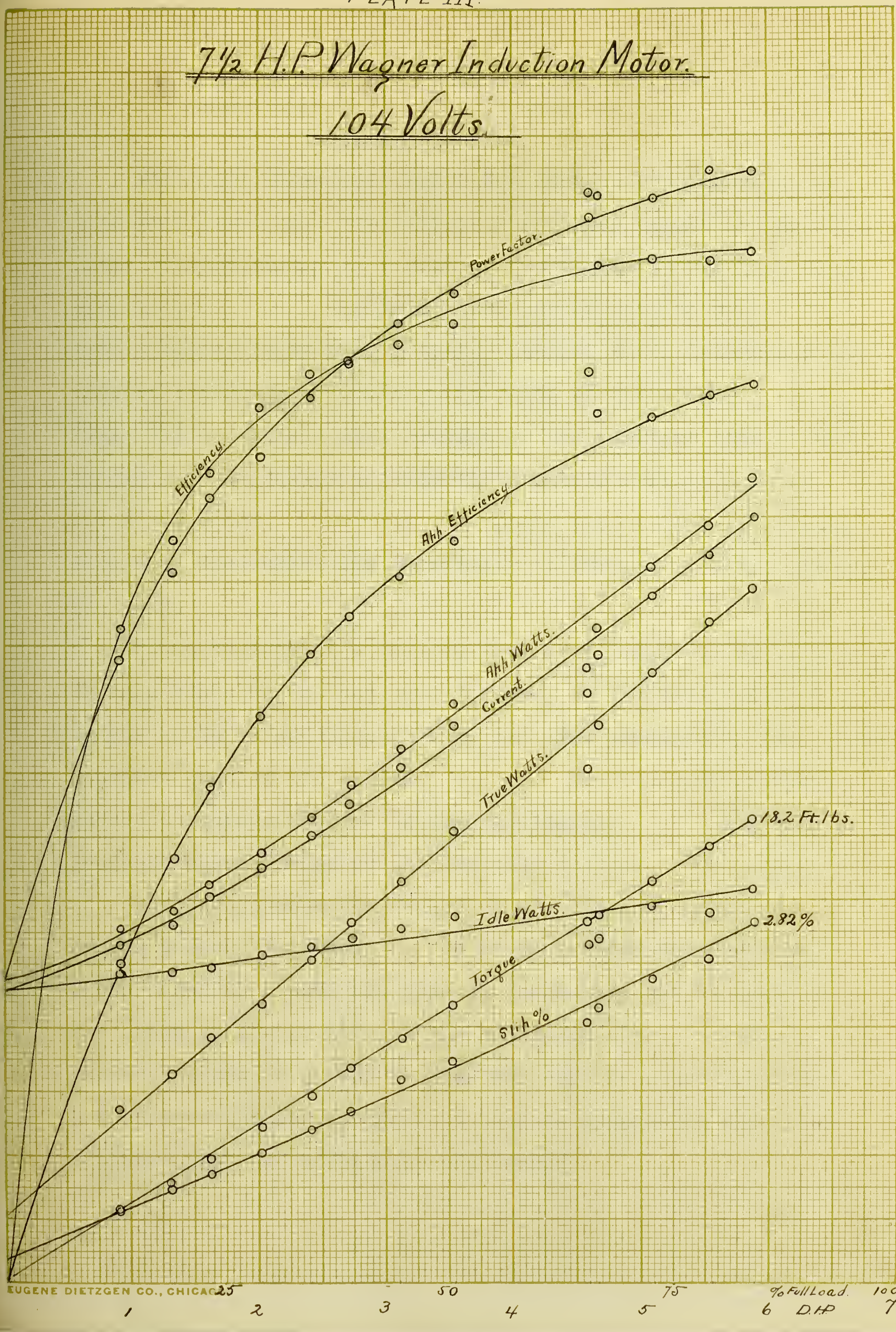

7½ H.P. Wagner Induction Motor.
104 Volts.
Power Factor.
Efficiency.
App. Efficiency.
App. Watts.
Current.
True Watts.
Idle Watts.
Torque
Slip %
18.2 Ft. lbs.
2.82 %
% Eff. Power Factor.
1/10 K.W.
80
70
60
50
40
30
20
10
EUGENE DIETZGEN CO., CHICAGO
25
50
75
100
% Full Load.
1
2
3
4
5
6
7
D.H.P.

Plate lV. shows idle watts and efficiency plotted on a true watt input base the maximum efficiency occurs on the lower voltage curves at a smaller input than on the high voltage curves. The idle watts curves seem to cross in such a manner as to have a common tangent which intersects the axis of ordinates on the negative side of the origin. In Plate V this tangent line crosses on the positive side of the origin and the curves of idle watts become flatter than in the 2 H.P.motor. In this Plate the highest efficiency occurs at lo4 volts, the efficiency at 120 and 90 being almost the same.

Plate Vl shows the same curves for a 7-½ h. p. motor and in this Plate we see the same tendency of the idle watts curves to form the tangent line, the line crossing on the positive side of the origin. The tendency of the curves to become flatter is also noticeable. The maximum efficiency being on the 12o volt curves.

Plate Vll shows the variation of slip and efficiency of the different motors. As might be expected the efficiency increases with the size of the motor, but is greater for loads as low as 15%, in the smaller sizes. The curves of slip show that it does not vary in a straight line but becomes greater as the full load is approached and rises rapidly after the machine is overloaded.

PLATE IV.

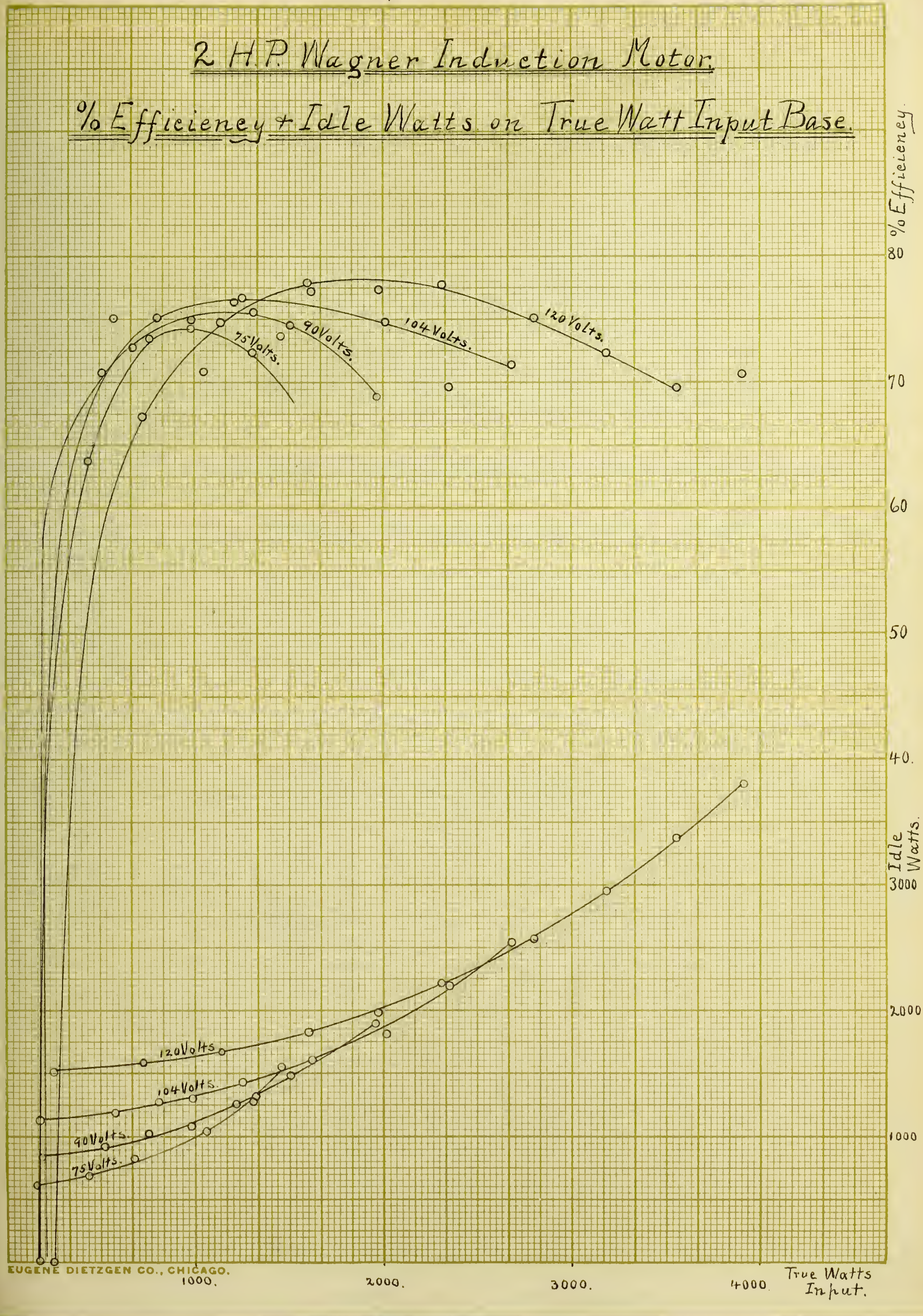

2 H.P. Wagner Induction Motor.
% Efficiency + Idle Watts on True Watt Input Base.
% Efficiency
80
70
60
50
40.
Idle Watts.
3000
2000
1000
120 Volts.
104 Volts.
90 Volts.
75 Volts.
120 Volts.
104 Volts.
90 Volts.
75 Volts.
1000.
2000.
3000.
4000.
True Watts Input.
EUGENE DIETZGEN CO., CHICAGO.

PLATE V.

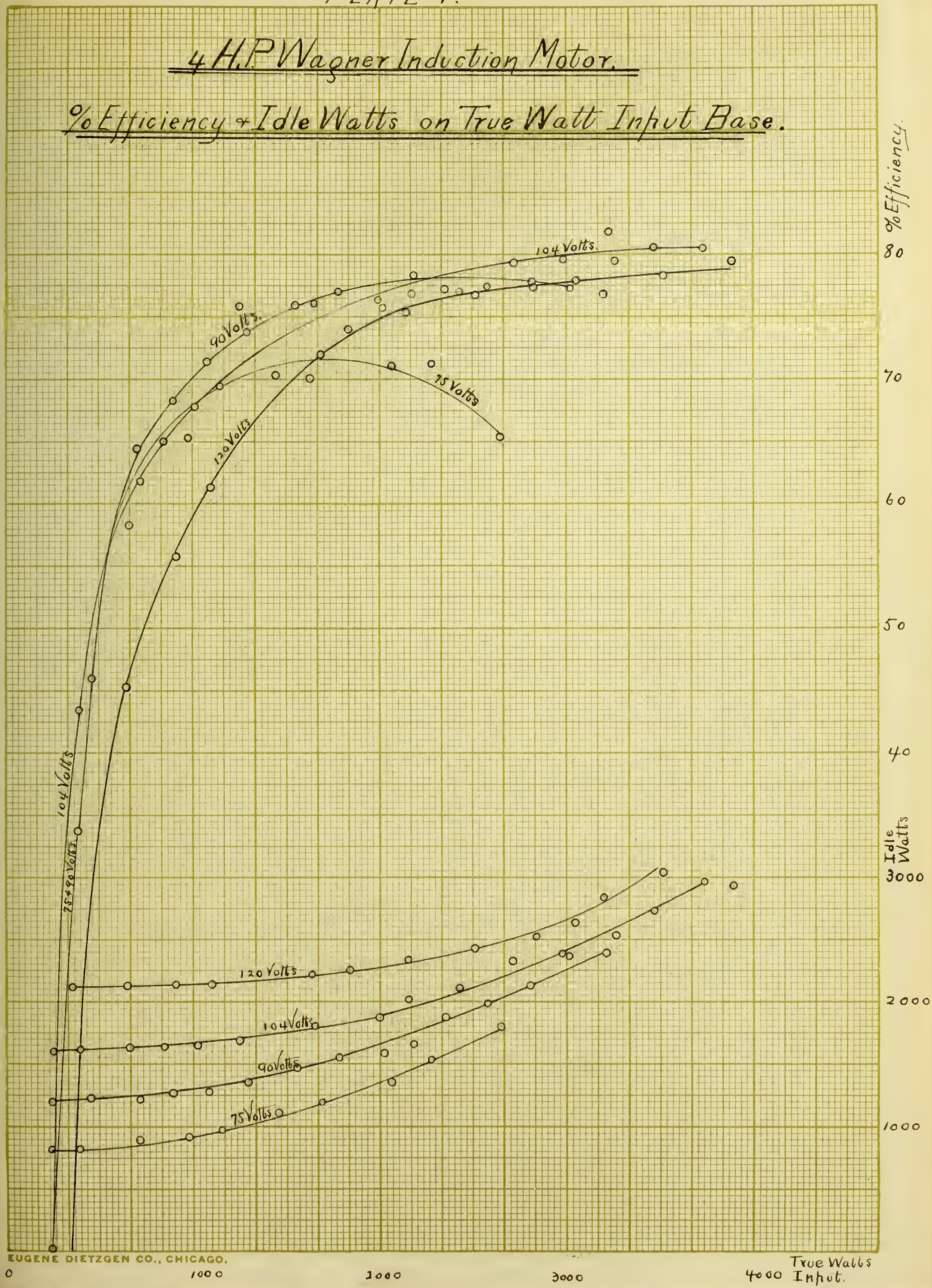

4 H.P. Wagner Induction Motor.
% Efficiency + Idle Watts on True Watt Input Base.
% Efficiency
80
70
60
50
40
104 Volts.
90 Volts.
120 Volts
75 Volts
104 Volts
75+90 Volts
Idle Watts
3000
2000
1000
120 Volts
104 Volts
90 Volts
75 Volts
EUGENE DIETZGEN CO., CHICAGO.
0
1000
2000
3000
4000
True Watts Input.

PLATE VI.

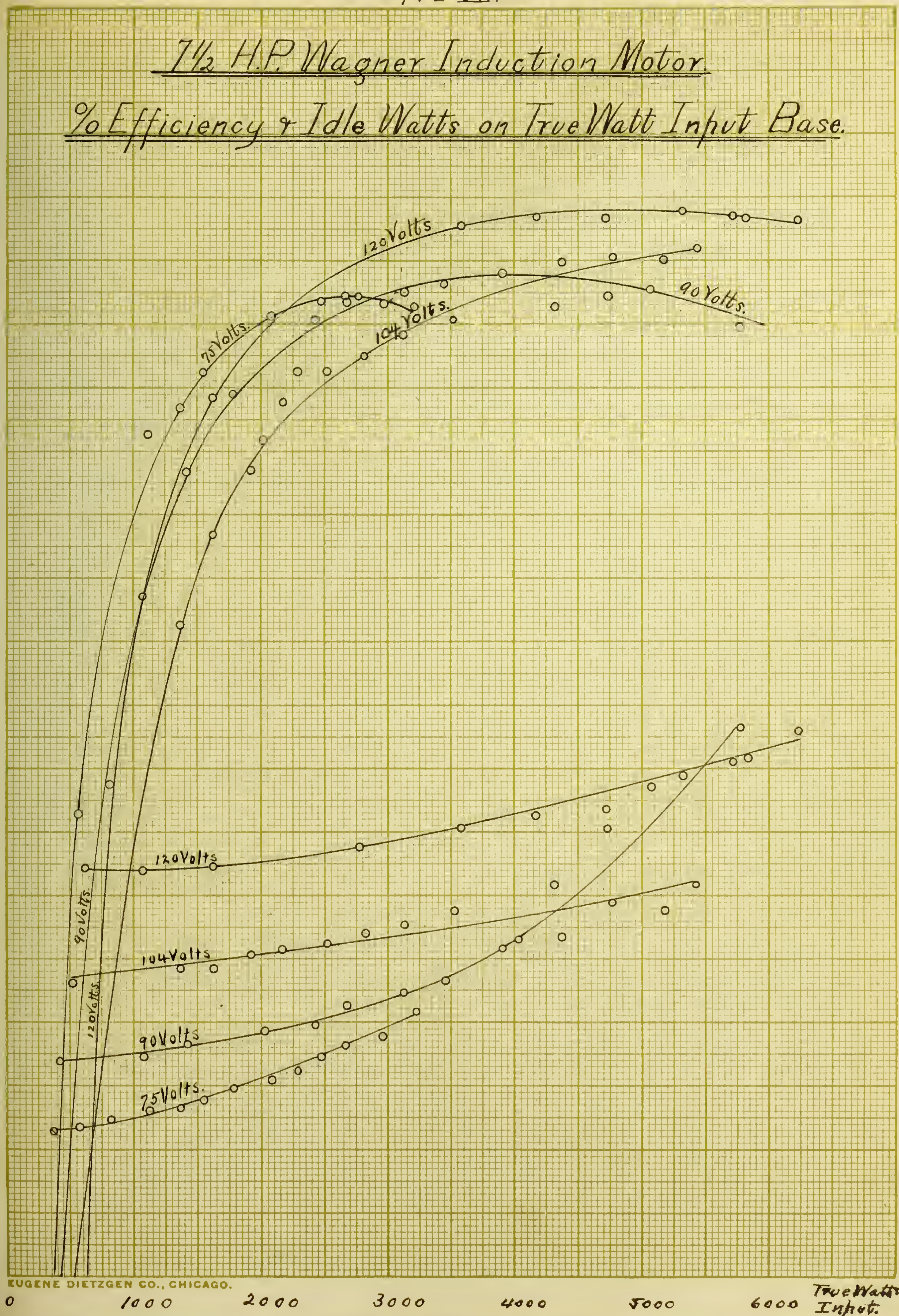
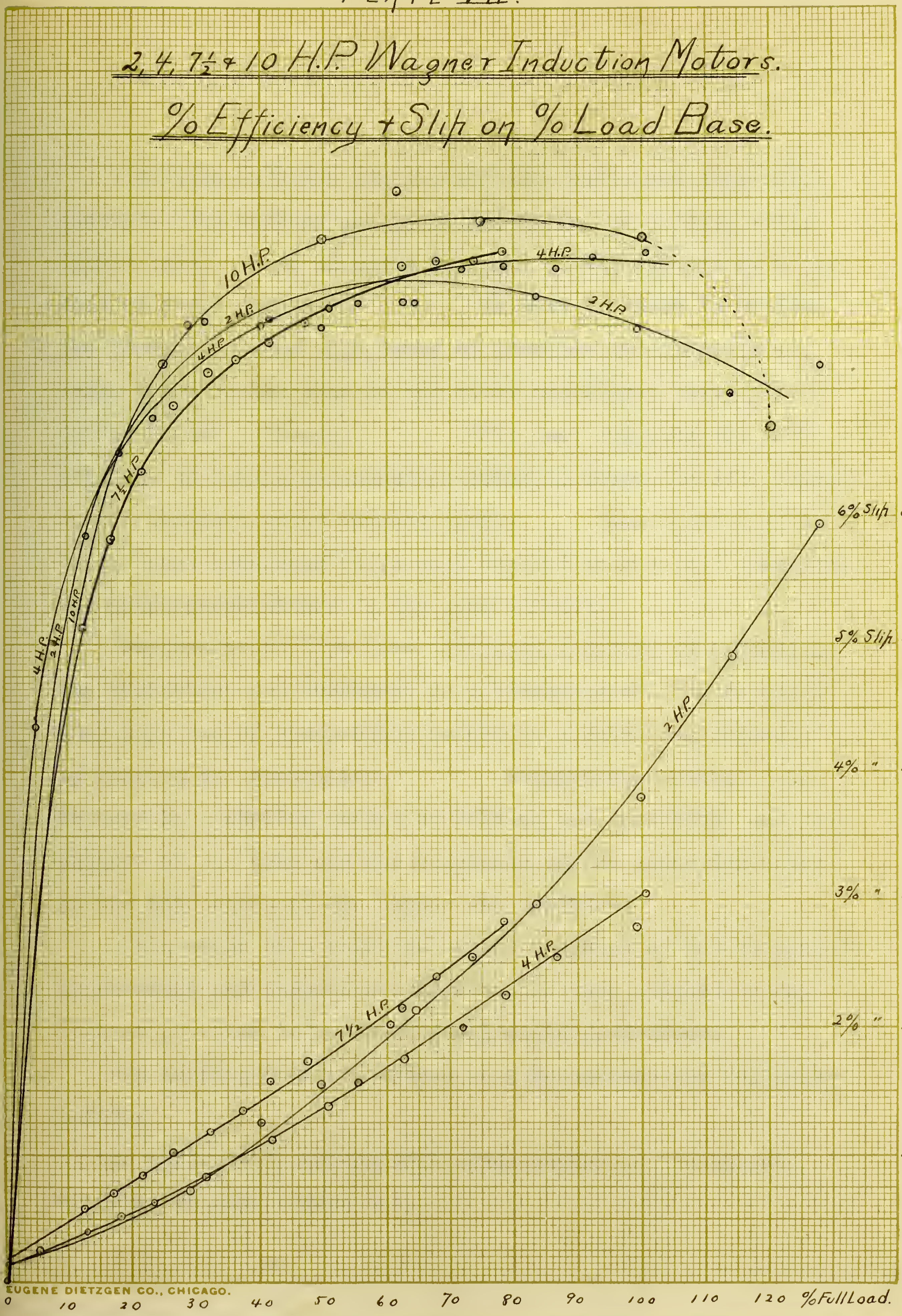

7½ H.P. Wagner Induction Motor.
% Efficiency & Idle Watts on True Watt Input Base.
% Efficiency
Idle Watts
120 Volts
104 Volts
90 Volts
75 Volts
80
70
60
50
4000
3000
2000
1000
0
1000
2000
3000
4000
5000
6000
True Watts Input.
EUGENE DIETZGEN CO., CHICAGO.

PLATE VII.


2, 4, 7½ + 10 H.P. Wagner Induction Motors.
% Efficiency + Slip on % Load Base.
% Efficiency
10 H.P.
4 H.P.
2 H.P.
7½ H.P.
10 H.P.
6% Slip
5% Slip
4% "
3% "
2% "
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
110
120
% Full Load.
EUGENE DIETZGEN CO., CHICAGO.

In Plate V111 are plotted the idle watts and true efficiency of the various motors at 104 Volts, on a "true watts input" base, Plate 1X shows the same curves plotted on a per cent of full load base. In both of these is noticed the tendency of the idle watts to increase less rapidly at large loads as the size of the motor increases, just as they do for higher voltages. This fact suggests the possibility of having an induction motor in which the idle watts remain constant under varying loads. Such a motor would be of great advantage if it were desired to run both induction and synchronous motors in the same circuit.

Steimnetz and Rice have developed a method of balancing the resistance and reactance of a transmission line in which they make use of synchronous motors as a balancing capacity by varying the excitation. Synchronous motors could be used in a similar manner to balance the resistance and reactance of the line and the reactance of the induction motor if the idle watts of the latter are constant.

This would be a solution of the question of how to operate synchronous and induction motors in the same circuit or any load at any time to approach ideal ohmic conditions.

In looking over the curves we have noticed the following points;

In two motors the maximum efficiency occurs at the highest voltage, in one it does not.

PLATE VIII.

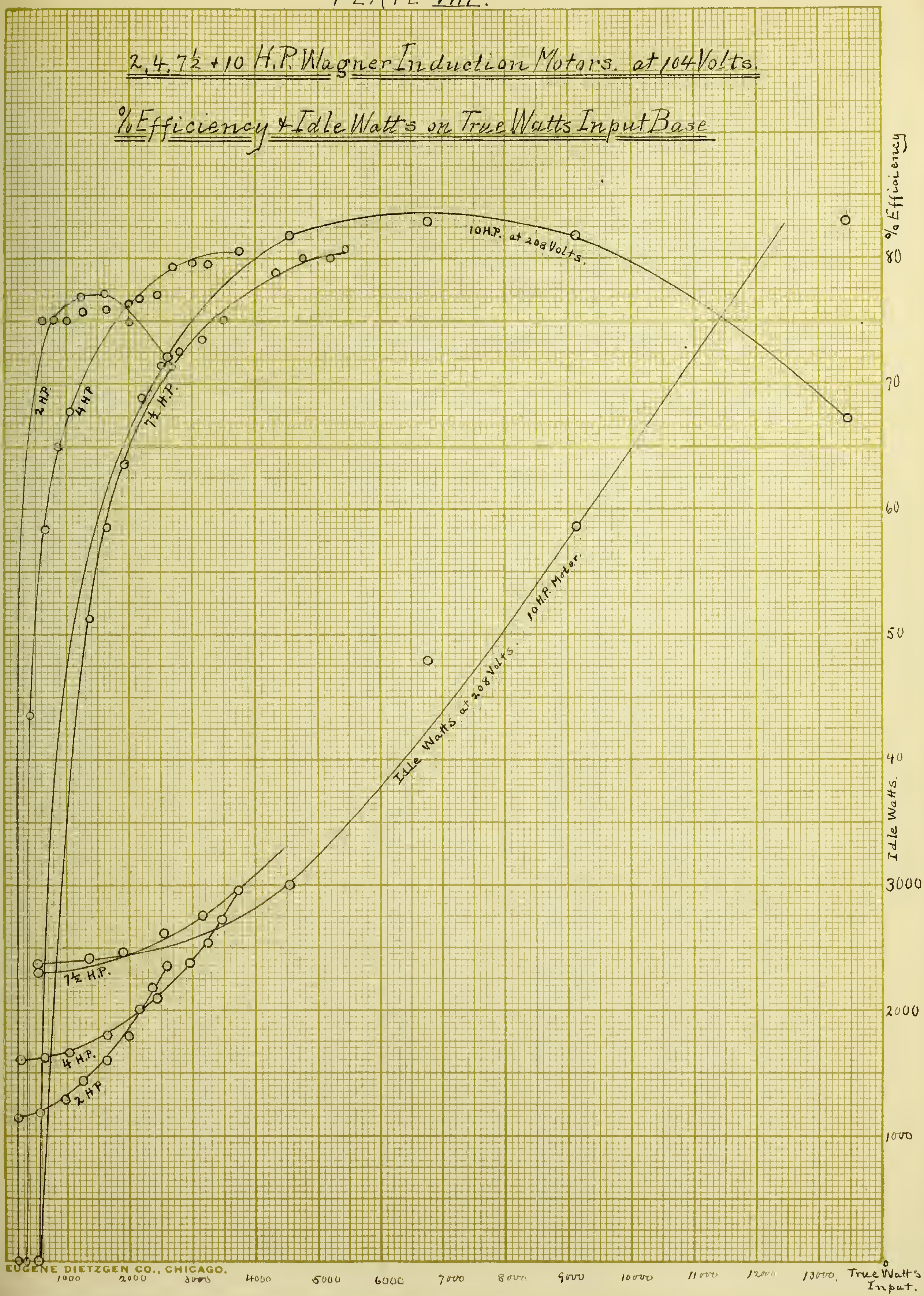
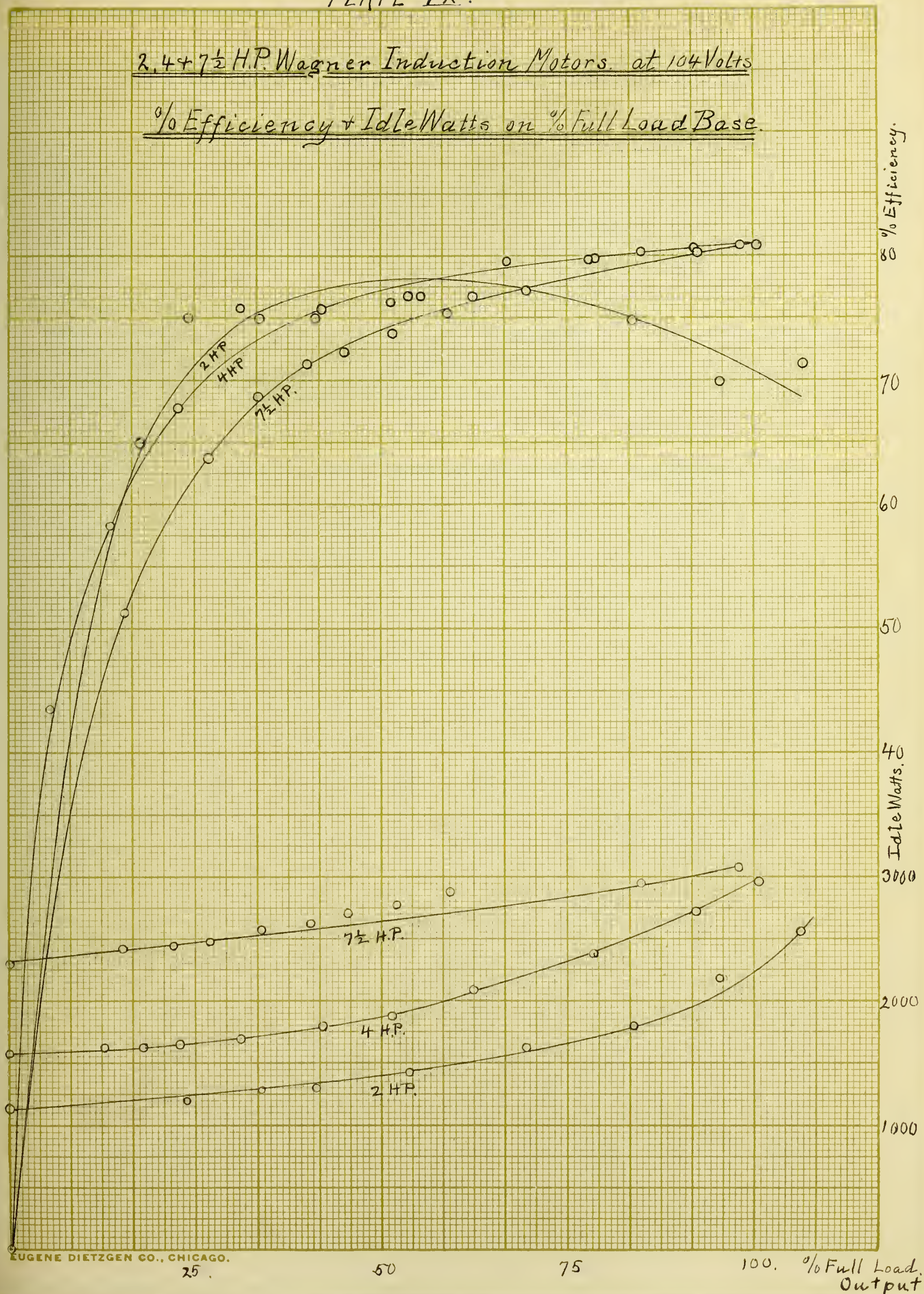
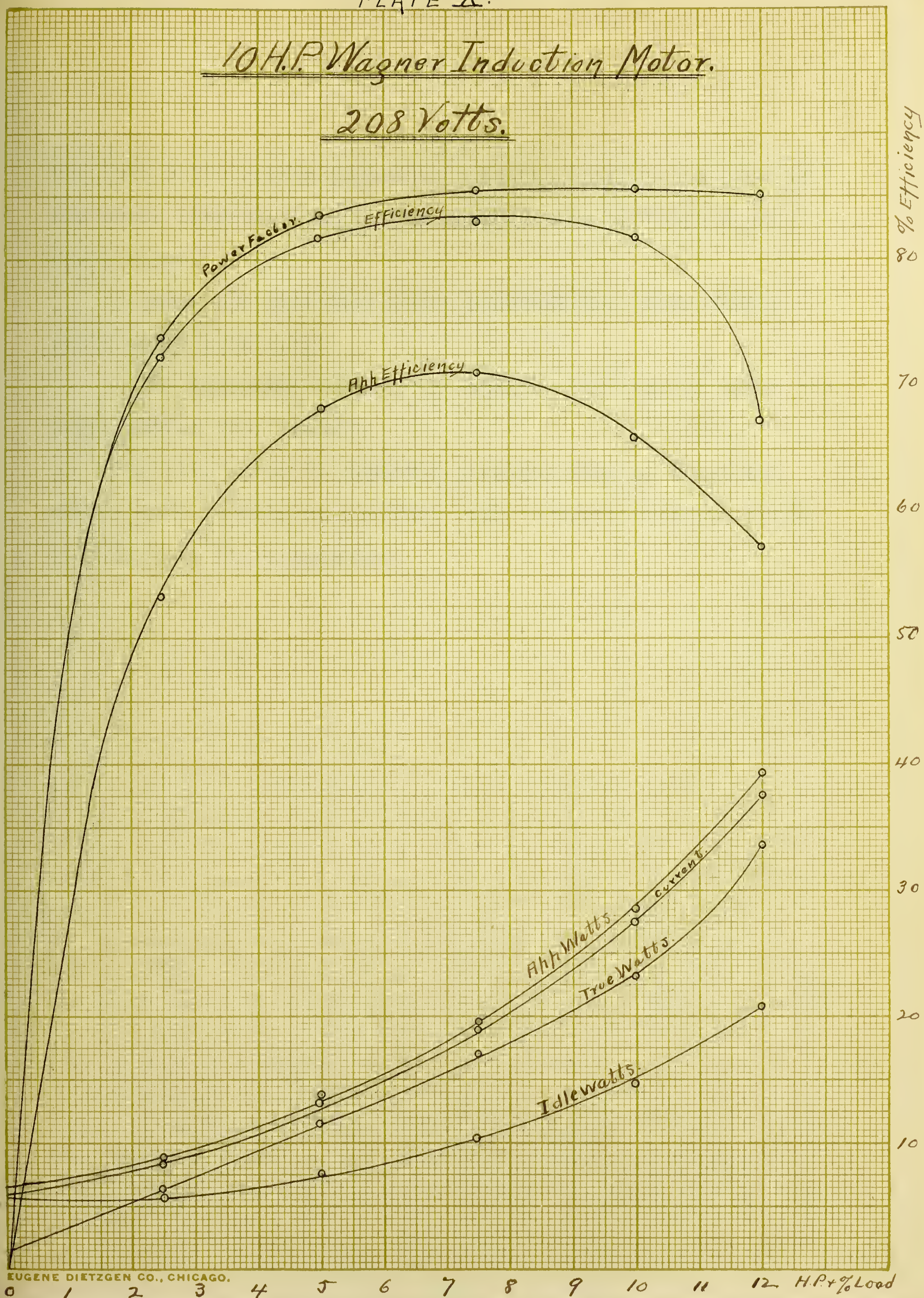

2, 4, 7½ + 10 H.P. Wagner Induction Motors. at 104 Volts.
% Efficiency & Idle Watts on True Watts Input Base
10 H.P. at 208 Volts.
2 H.P.
4 H.P.
7½ H.P.
Idle Watts at 208 Volts. 10 H.P. Motor.
% Efficiency
Idle Watts.
80
70
60
50
40
3000
2000
1000
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
True Watts Input.
EUGENE DIETZGEN CO., CHICAGO.

PLATE IX.



2, 4 + 7½ H.P. Wagner Induction Motors at 104 Volts
% Efficiency + Idle Watts on % Full Load Base.
% Efficiency.
Idle Watts.
2 H.P.
4 H.P.
7½ H.P.
80
70
60
50
40
3000
2000
1000
25
50
75
100.
% Full Load Output
EUGENE DIETZGEN CO., CHICAGO.

PLATE X.


10 H.P. Wagner Induction Motor.
208 Volts.
Power Factor.
Efficiency
App Efficiency
App Watts.
Current.
True Watts.
Idle watts.
% Efficiency
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
H.P. + % Load
EUGENE DIETZGEN CO., CHICAGO.

The idle watts curves flatten out as the voltage and size of the motor increases but do not seem to ever approach a constant value.

In case the idle watts were constant the power factor would never bend over.

The lower the voltage the smaller the load at which the power factor is a maximum.

The slip curve is almost a straight line at first but curves more rapidly as the full load is approached and rises quickly when it is exceeded.

THEORETICAL

As stated elsewhere in this thesis the method usually used in the theoretical consideration of the induction motor is the one in which the motor is considered as a transformer, having a movable secondary circuit. If now we let

p = number of equal circuits on primary

n = " " primary turns per circuit

and let the corresponding terms for the secondary be represented by the same symbols with the subscript "1" then

$\frac{np}{n_1 p_1} = a$ = the ratio of total primary turns to total secondary turns.

It is preferable to reduce all secondary quantities to the primary system by the ratio of transformation "a"; since the number of secondary circuits and the number of turns per secondary circuit is unessential; then if E_1' is the secondary E. M. F per circuit, $E_1 = aE_1'$ = secondary E.M.F. per circuit reduced to primary system. Similarly

$I_1 = \frac{I_1'}{a}$ = secondary current per circuit

$r_1 = a^2 r_1'$ = secondary resistance per circuit

$x_1 = a^2 x_1'$ = secondary reactance per circuit

$z_1 = a^2 z_1'^2$ = secondary impedance per circuit

all reduced to primary system

Let Φ = total maximum flux of the magnetic field, per motor pole and N = frequency of primary impressed E. M. F.

Then $E = \sqrt{2}\,\pi n N \Phi 10^{-8}$ is the effective electromotive force induced by the magnetic field per primary

circuit and $E = -e$ where $e = \sqrt{2}\, \eta\, n\, N \Phi 10^{-8}$ may be considered as the active electromotice force of the motor and $\Phi = j\varphi$ in complex quantities time being counted from the moment where the flux, Φ, interlinked with both primary and secondary circuits passes through zero.

Since the secondary frequency is sN, the secondary induced E. M. F. (reduced to primary system) is $E_1 = -se$

While there are numerous formulae relating to the induction motor the ones most interesting to us were the formulae for torque and power and these were selected for comparing the theoretical and observed values.

The torque of any motor is dependent upon the number of armature conductors, the current flowing in them and the strength of the enveloping magnetic field and the sine of the angle between them. Therefore, in the induction motor if

$\frac{\varphi}{\sqrt{2}}$ = the effective magnetism developed in a single pole

$\frac{F_1}{\sqrt{2}}$ = the effective rotor magneto motive force and

$\sin(\varphi F_1)$ = the sine of the angle between them, and T' be the torque we have

$$T' = \frac{\varphi F_1}{2} \sin(\varphi F_1)$$

also if n_1 = the number of turns

I_1 = current per circuit and

p = the number of armature circuits

we have for the value of the armature magneto motive force

$$F_1 = \frac{p\, n_1 I_1}{\sqrt{2}}$$

and substituting this in the above formula gives

$$T' = \frac{\Phi p n_1 I_1 \sin(\Phi F_1)}{2\sqrt{2}}$$

and since there are "d" poles the total torque T becomes -

$$T = \frac{d \Phi p n_1 I_1 \sin(\Phi F_1)}{2\sqrt{2}}$$

The electromotive force E_1 induced in the rotor is 90° behind the inducing magnetism hence it reaches a maximum when the inducing magnetism is zero. There is also a lag of the current in the rotor due to the impedance of the rotor coils and if the lag of this be w_1 the total lag of the current in the rotor behind the field or stator magnetism is $(90^\circ + w_1)$ The sine of this is equal to cosine w_1 and the cosine w_1 is $\frac{r_1}{\sqrt{r_1^2+s^2x_1^2}}$; since the tangent of the lag angle equals the reactance over the resistance or $\frac{sx_1}{r_1}$ and $\cos = \frac{1}{\sqrt{1+\tan^2}}$.

The current in the rotor coils is equal to the electromotive force induced in the rotor windings divided by the impedance. Since the frequency of the E. M. F. of the rotor depend s on the slip, the impedance must also depend on the slip and, therefore, the slip must be a factor of the expression for rotor current; hence when reduced to primary system we have current in rotor

$$I_1 = \frac{es}{\sqrt{r_1^2+s^2x_1^2}}$$

since "e" is the electromotive force induced per turn by the

mutual magnetic flux the total "e" must be equal to the number of turns in series per circuit multiplied by the flux and the frequency. If

n_1 = number of turns in series

ϕ = the flux and

N = the frequency

we have for one circuit

$$e = \frac{\sqrt{2}\,\eta\, n_1 \phi N}{10^8} \quad \text{or} \quad \phi = \frac{e\,10^8}{\sqrt{2}\,\eta N n_1} \text{ therefore}$$

taking the equation for torque

$$T = \frac{d\,\phi\, p\, n_1 I_1 \sin(\phi F_1)}{2\sqrt{2}} \quad \text{or} \quad T = \frac{d\,\phi\, p\, n_1 I_1 \cos w_1}{2\sqrt{2}}$$

and substituting we have $T = \dfrac{d\, p\, r_1\, s\, e^2 10^8}{4\eta N(r_1^2 + s^2 x_1^2)}$

by means of which we can determine the torque if we know the value of "e" Before proceeding to evaluate "e" let us consider what the output of the motor will be.

At a unit radius the circumference of a circle is 2π and since the speed of an induction motor $= \dfrac{2N(1-s)}{d}$ where N = frequency and d = the number of poles + s the slip, the linear distance passed over by a point on the circumference in one second is $\dfrac{4\pi N(1-s)}{d}$ and if T is the torque, the output of the motor will be $\dfrac{T 4\eta N(1-s)}{d}$ or substituting for T the value already found we have the output or power

$$P = \left[\frac{4\pi N(1-s)}{d}\right]\left[\frac{d\, p\, r_1\, s\, e^2 10^8}{4\eta N(r_1^2 + s^2 x_1^2)}\right]$$

which reduces to $P = \frac{p r_1 s e^2 (1-s) 10^8}{r_1^2 + s^2 x_1^2}$

We can now determine power and torque if we can evaluate "e"

As the rotor revolves there is a back E. M. F. induced in the stator coils by the cutting of them by the flux due to the rotor current, and since "e" is defined as the electromotive force induced per turn by the mutual magnetic flux we have $-E_B = e$ Now the applied electromotive force at the terminals must be sufficient to overcome this back E. M. F? and also to overcome the impedance drop, hence the applied E. M. F.

$$E_0 = E_B + E_z$$

or $$E_0 = e + E_z$$

E_z = the E. M. F. consumed by the primary impedance and is therefore $= IZ$ but I is composed of two parts, an exciting current $I_0 = eY$ where Y is the admittance of the primary, and a component corresponding to the secondary current or $I_1' = \frac{se}{r_1 - jsx_1}$

hence the total primary current $= I = I_1' + I_0$

$$= e\left[\frac{s}{r_1 - jsx_1} + (g + jb)\right]$$

since Y the admittance $= (g + jb)$

substituting these in $E_z = ZI$ we have

$$E_z = Ze\left[\frac{s}{r_1 - jsx_1} + (g + jb)\right] = e(r - jx)\left[\frac{s}{r_1 - jsx_1} + (g + jb)\right]$$

and since $E_0 = e + E_z$ we have

$$E_0 = e\left[1 + \frac{s(r - jx)}{r_1 - jsx_1} + (r - jx)(g + jb)\right]$$

or

approximately $E_0 = e\left[1 + \frac{s(r - jx)}{r_1 - jsx_1}\right]$ Solving for e we get

$$e = E_0 \sqrt{\frac{r_1^2 + s^2 x_1^2}{(r_1 + sr)^2 + s^2(x_1 + x)^2}}$$

in real values, which are obtained by taking the square root of the sums of the squares of the imaginary values; and substituting this value of "e" in the formulae for torque and power we have

$$T = \frac{d\,p\,r_1 E_0^2 s}{4\pi N\left[(r_1 + sr)^2 + s^2(x_1 + x)^2\right]}.$$

$$P = \frac{p\,r_1 E_0^2 s(1 - s)}{(r_1 + sr) + s^2(x_1 + x)^2}.$$

MECHANICAL & ELECTRICAL DATA ON WAGNER INDUCTION MOTORS.

	2 H.P	4 H.P.	7½ HP	10 H.P.
Manufacturers No.	AC. 1	AC 2a	AC. 3½	AC. 5.
Serial No.	581	719	807	868
Type of Machine	Single Ph.	Sin Ph.	Sin Ph.	Sin. Ph.
Number of Poles	4	4	4	4
Capacity H.P.	2	4	7½	10.
Speed R.p.m. no load	1800	1800	1800	1800.
Speed R.p.m. full load	1718	1747	1740.	1725
Frequency in cycles	60	60.	60	60.
Volts, normal	104	104	104	104
Volts, no load	"	"	"	"
Volts full load	97	80	-	-
~~Starting~~ current full load	24	44	78	100.
Current - no load - Amp.	16	15	21	33.

A Rotor.

Peripheral velocity - ft per sec.	64.3	64.2	86.08	86.08
Diameter over all	8.19"	8.17"	10.96"	10.96".
Diam. of core, internal	4.07"	4.05"	4.96"	4.96"
Length of core over all	3.4"	3.4"	4.75"	4.75"
Thickness of Laminae	#26 B+S	#26 B+S	#26 B+S	#26 B+S
Width of slots	9/32"	9/32"	9/32"	9/32"
Depth of slots	1.06"	1.06"	1.12"	1.12"
Number of Slots	47	47	65	65
Width of tooth, minimum	11/64"	11/64"	13/64"	13/64"
" " " at root	11/64"	11/64"	13/64"	13/64"
" " " at surface	7/16"	7/16"	7/16"	7/16"

	2 HP	4 HP	7½ HP	10 HP
Size of wire	#12	#12	#11	#11
Insulation	Fuller Board			
Number of coils, per slot	4	4	4	4
" " conductors, per slot	16	16	8	8
" " turns, per coil	2	2	1	1
" " wires in multiple	2	2	2	2
Air gap	.0215	.021	.022	
Resistance Brush to Brush.	.078			

B Stator

	2 HP	4 HP	7½ HP	10 HP
External diameter	12.98	12.96	16.5	
Resistance	.182 Loop. .155			
Internal "	8.23	8.21	11.	
Impedance	1.37			
Length of core	3.4	3.4	4.75	4.75
Thickness of laminae	#26	#26	#26	#26
Number of slots	40	40	56	56
Depth of slots	1.25	1.25	1.25	1.25
Width of slots	7/16	7/16	7/16	7/16
Insulation	Fuller Board + Duck			
Width of tooth, minimum	0.26	.26		
" " " at root	.46	.46		
" " " at surface	.52	.52		
Polar embrace	360°	360°	360°	360°
Length of polar arc	90°	90°	90°	90°
Size of wire	#11	#13	#11.	
Number of turns per slot	21	12½	14½	
" " " " pole	210	125	145	
" " wires " slot	21	25	14½.	
" " " " multiple	1	2	1	
Loop after Turn No.	18	11	12½	
Number of Poles in Series	2	2	1	1

	2 H.P.	4	7½	10
C Commutator.				
Diameter, External	$7\frac{13}{16}$	$7\frac{13}{16}$	10.5	10.5
" Internal	$3\frac{5}{8}$	$3\frac{5}{8}$	5.	5
Length - radial	$2.\frac{3}{32}$	$2\frac{3}{32}$	2.75	2.75
" ~~axial~~ active	1.5	1.5	$2\frac{1}{16}$	$2\frac{1}{16}$
Maximum width of segment	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{15}{64}$	$\frac{15}{64}$
Minimum " " "	$\frac{3}{32}$	$\frac{3}{32}$	$\frac{6}{64}$	$\frac{6}{64}$
Thickness of mica between segments	.04	.04	$\frac{1}{32}$	$\frac{1}{32}$
Number of segments	93	93	129.	129
" " " per slot	$\frac{93}{47}$	$\frac{93}{47}$	$\frac{129}{65}$	$\frac{129}{65}$
" " " covered by brushes	2	1	1	1
" " - - - wires per segment	4	4	4	4
D. Brushes.				
Number	2	4	4	4
Length radial	1.5	1.5	2.06	2.06
Width maximum	$\frac{7}{32}$	$\frac{9}{32}$	$\frac{9}{32}$	$\frac{9}{32}$
" minimum	$\frac{3}{32}$	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{5}{32}$
Area of contact	.23 □"	.33 □"	.44 □"	.44 □"
Type of brush	Carbon	—	—	—
Electrical Data				
Rotor				
Resistance, cold. Brush to Brush.	.078			

2 H.P. Wagner Induction Motor.

Volts Constant at 75. Speed 1760 R.P.M.

A.C. Ammeter 13457.

A.C. Voltmeter 857.

A.C. Wattmeter 775.

No	Amp	True Watts	Pull in Pounds	Slip R.P.M.	Slip %	App Watts	H.P.	True Eff	App Eff	Power Factor	Induc Factor	Idle Watts.
1	8.4	165	0	8	.454	630	0	0	0	.262	.965	607
2	10.9	435	2.25	28	1.59	818	.371	.636	.339	.532	.847	693
3	14.1	675	4.03	46	2.61	1058	.658	.728	.564	.638	.769	814
4	19.8	1055	6.25	80	4.54	1484	1.00	.708	.503	.712	.702	1042
5	24.5	1305	7.75	124	7.05	1838	1.27	.724	.514	.710	.704	1293
6	28.1	1455	8.93	150	8.52	2108	1.437	.737	.508	.691	.722	1545

2 H.P. Wagner Induction Motor.

Volts Constant at 90
A.C. Ammeter 13457
A.C. voltmeter 857
A.C. Wattmeter 775

Speed 1760 R.P.M.

May 26 1900

No	Amp	True Watts	Pull in Pounds	Slip R.P.M	Slip %	App Watts	H.P.	True Eff	App Eff	Power Factor	Induc. Factor	Idle Watts
1	9.6	185	0	6	.341	.864	0	0	0	.214	.977	844
2	11.8	515	2.95	24	1.36	1061	.488	.707	.343	.485	.874	927
3	14.1	755	4.53	34	1.96	1268	.745	.735	.438	.596	.802	1017
4	16.3	985	6.01	46	2.61	1467	.982	.743	.499	.671	.741	1088
5	19.4	1215	7.69	62	3.52	1745	1.24	.764	.532	.696	.718	1253
6	20.9	1325	8.32	70	3.97	1880	1.34	.755	.533	.705	.709	1333
7	23.5	1505	9.44	84	4.77	2115	1.505	.746	.532	.712	.702	1485
8	30.4	1965	11.44	120	6.82	2735	1.79	.679	.488	.719	.695	1900

2 H.P. Wagner Induction Motor.

Volts Constant at 104 — Speed 1760 R.P.M.

A.C. Ammeter 13457

A.C. Voltmeter 857

A.C. Wattmeter 775

May 26. 1900.

No	Amp	True Watts	Pull in Pounds	Slip R.P.M.	Slip %	App Watts	H.P.	True Eff.	App Eff.	Power Factor	Induc Factor	Idle Watts
1	11.1	205	0	4.47	.254	1155	0	0	0	.1775	.984	1134
2	12.8	575	3.2	16.	.742	1330	.58	.75	.376	.432	.900	1196
3	14.4	805	4.9	27.	1.25	1497	.808	.75	.40	.537	.843	1263
4	15.7	995	6.08	34.	1.57	1632	.99	.749	.456	.608	.793	1293
5	18.3	1255	7.94	46.	2.13	1902	1.29	.767	.506	.660	.752	1430
6	21.9	1615	10.37	64	2.96	2275	1.67	.772	.548	.710	.704	1602
7	26.4	2005	12.62	82	3.80	2744	2.01	.748	.547	.7315	.682	1800
8	30.7	2345	14.5	106	4.91	3215	2.28	.696	.529	.7310	.683	2192
9	35.3	2675	16.5	128	5.94	3700	2.56	.714	.516	.723	.689	2540

2 H.P. Wagner Induction Motor.

Volts Constant at 120. Speed 1760 R.P.M.

A.C. Ammeter 13457

A.C. Voltmeter 857

A.C. Wattmeter 775

May 26 1900.

No	Amp	True Watts	Pull in Pounds	Slip R.P.M.	Slip %	App Watts	H.P.	True Eff	App Eff	Power Factor	Induc Factor	Idle Watts
1	12.7	255	0	3.66	.208	1523	0	0	0	.167	.986	1502
2	14.5	725	3.95	17.	.966	1740	.656	.674	.281	.416	.909	1582
3	16.7	1135	6.89	28.	1.59	2005	1.135	.746	.422	.566	.824	1652
4	20.2	1595	10.19	44.	2.5	2425	1.663	.778	.511	.658	.752	1822
5	23.4	1985	12.69	56	3.18	2805	2.06	.774	.548	.708	.706	1980
6	27.	2315	14.94	68	3.86	3220	2.41	.777	.559	.719	.694	2233
7	31.6	2795	17.69	90	5.11	3790	2.81	.75	.553	.738	.675	2558
8	36.3	3185	19.69	110	6.25	4360	3.09	.723	.529	.731	.682	2970
9	40.8	3545	21.31	130	7.39	4890	3.31	.696	.505	.725	.688	3365
10	45.4	3905	22.88	146	8.29	5450	3.70	.707	.506	.717	.697	3800

4 H.P. Wagner Induction Motor.

Volts Constant at 75. Speed 1745

A.C. Ammeter 13457

A.C. Voltmeter 857

A.C. Wattmeter 775 May 8. 1900.

No	Amp	True Watts	Pull in Pounds	Slip R.P.M.	Slip %	App Watts	H.P.	True Eff	App. Eff.	Power Factor.	Induc. Factor	Idle Watts
1	11.2	245	0	3.34	.193	840	0	0	0	.291	.957	.804
2	12.2	395	1.09	6.74	.387	914	.1805	.341	.147	.432	.902	.824
3	15.3	705	3.70	14.3	.82	1145	.61	.645	.403	.626	.780	.893
4	17.8	975	5.19	20.	1.147	1335	.851	.651	.476	.731	.682	.910
5	20.2	1155	6.57	25.	1.433	1515	1.075	.695	.529	.763	.646	.979
6	24.3	1455	8.38	33.3	1.92	1825	1.366	.701	.558	.798	.603	1100
7	27.5	1685	10.00	39.4	2.26	2065	1.62	.718	.587	.817	.577	1190
8	32.8	2055	12.13	49.6	2.84	2460	1.95	.71	.593	.835	.550	1353
9	36.6	2275	13.57	58.8	3.37	2740	2.17	.712	.593	.831	.556	1521
10	42.8	2655	14.59	73.8	4.23	3210	2.32	.652	.539	.827	.562	1804

4 H.P. Wagner Induction Motor

Volts Constant at 90 Speed 1745

A.C. Ammeter 13457

A.C. Voltmeter 857

A.C. Wattmeter 775

May 7, 1900.

No.	Amp.	True Watts	Pull in Pounds	Slip RPM	Slip %	App Watts	H.P.	True Eff.	App Eff.	Power Factor	Induc. Factor	Idle Watts
1	13.6	235	0	2.26	.129	1223	0	0	0	.19	982	1200
2	14.6	455	1.69	5.56	.39	1312	.28	.459	.159	.346	.938	1230
3	15.7	725	3.71	10.45	.599	1411	.60	.617	317	.513	.858	1210
4	17.1	895	5.00	13.05	.748	1540	.82	.683	.398	.581	.814	1253
5	18.6	1085	6.37	16.7	.921	1672	1.04	.714	.455	.649	.761	1272
6	20.8	1295	7.81	20.2	1.15	1872	1.28	.736	.48	.691	.723	1354
7	23.7	1555	9.69	24.8	1.42	2135	1.58	.76	.552	.728	.686	1463
8	26.2	1785	11.25	28.6	1.64	2360	1.84	.77	.582	.756	.655	1545
9	28.3	2025	12.81	32.6	1.87	2575	2.09	.757	.606	.786	.618	1590
10	30.4	2185	14.06	36.4	2.09	2735	2.29	.782	.625	.798	.603	1650
11	33.5	2375	15.19	40.8	2.34	3015	2.46	.773	.608	.787	.617	1860
12	36.1	2575	16.56	46.2	2.65	3250	2.68	.775	.615	.793	.609	1980
13	39.2	2805	16.94	50.8	2.91	3525	2.74	.778	.650	.795	.607	2135
14	43.4	3015	19.40	56.6	3.24	3905	3.13	.774	.598	.772	.636	2365
15	44.4	3211	20.19	63.1	3.62	4000	3.51	.817	.655	.80	.599	2395

4 H.P. Wagner Induction Motor.

Volts Constant at 104 — Speed 1745 R.P.M.

A.C. Ammeter 13457

A.C. Voltmeter 857

A.C. Wattmeter 775 — May 7, 1900.

No	Amp.	True Watts	Pull in pounds	Slip R.P.M.	Slip %	App. Watts	H.P.	True Eff	App. Eff	Power Factor	Induc. Factor	Idle Watts
1	15.6	265	0	1.7	.0975	1620	0	0	0	.163	.986	1597
2	16.	395	1.37	4.05	.232	1660	.23	.435	.1031	.237	.971	1610
3	16.9	665	3.15	7.14	.409	1756	.52	.583	.2205	.378	.926	1627
4	17.7	845	4.44	9.1	.521	1840	.73	.65	.298	.459	.888	1634
5	18.7	1025	5.68	11.3	.648	1945	.93	.677	.34	.520	.853	1658
6	20.2	1245	7.69	14.3	.821	2100	1.26	.756	.448	.592	.805	1690
7	23.5	1655	10.31	19.35	1.11	2440	1.68	.758	.51	.674	.738	1800
8	26.3	1995	12.44	24.	1.376	2730	2.04	.763	.557	.730	.683	1866
9	28.3	2155	13.56	27.25	1.56	2940	2.21	.767	.562	.732	.681	2005
10	30.9	2425	15.56	30.57	1.75	3210	2.50	.769	.58	.755	.655	2100
11	34.3	2705	17.69	34.75	1.99	3565	2.88	.795	.602	.758	.651	2320
12	36.7	2975	19.44	39.3	2.25	3815	3.15	.796	.633	.78	.624	2380
13	39.7	3265	21.44	44.4	2.55	4125	3.47	.795	.627	.79	.612	2527
14	42.7	3465	22.88	48.7	2.79	4440	3.69	.805	.633	.787	.616	2735
15	46.	3725	24.88	53.2	3.05	4784	4.02	.8056	.628	.780	.624	2960

4 H.P. Wagner Induction Motor

Volts Constant at 120

A.C. Ammeter 13457

A.C. Voltmeter 857

A.C. Wattmeter 775

Speed 1745

May 8, 1900

No	Amp	True Watts	Pull in Pounds	Slip R.P.M.	Slip %	App Watts	H.P.	True Eff.	App Eff	Power Factor	Induc Factor	Idle Watts
1	18	355	0	1.58	.0906	2160	0	0	0	.1644	.986	2128
2	18.5	655	2.4	4.	.229	2220	.3975	.452	.133	.295	.955	2120
3	19.4	915	4.13	6.38	.366	2330	.682	.556	.218	.393	.919	2140
4	20.1	1105	5.5	8.57	.491	2415	.909	.613	.28	.457	.889	2145
5	23.	1635	9.32	13.32	.763	2760	1.535	.70	.415	.593	.805	2215
6	24.2	1835	11.07	15.	.86	2905	1.820	.739	.467	.632	.775	2250
7	26.5	2155	13.25	18.75	1.075	3180	2.175	.753	.511	.678	.735	2335
8	29.1	2505	15.69	22.25	1.275	3490	2.57	.766	.549	.718	.696	2425
9	31.6	2835	18.00	25.	1.433	3790	2.94	.773	.578	.748	.664	2515
10	33.5	3035	19.32	28.	1.605	4020	3.16	.776	.589	.756	.655	2630
11	35.7	3195	20.5	31.2	1.789	4280	3.28	.766	.572	.747	.665	2848
12	38.7	3515	22.69	35.9	2.059	4640	3.69	.783	.593	.757	.653	3030
13	40.3	3885	25.56	40	2.29	4835	4.14	.795	.639	.793	.609	2940

7½ H.P. Wagner Induction Motor.

Volts Constant at 75
A.C. Ammeter 13472
A.C. Voltmeter 857
A.C. Wattmeter 775

Speed 1745 R.P.M.

May 16. 1900.

No	Amp	True Watts	Pull in Pounds	Slip R.P.M.	Slip %	App Watts	H.P.	True Eff.	App Eff	Power Factor	Induc Factor	Idle Watts
1	15.9	345	0	4.23	.24	1192	0	0	0	.289	.957	1140
2	17.3	555	1.64	7.6	.44	1298	.271	.364	.156	.427	.905	1175
3	19.6	835	2.63	12.38	.71	1469	.433	.387	.22	.568	.823	1210
4	22.8	1135	6.13	18.18	1.04	1720	1.01	.664	.438	.66	.751	1290
5	25.3	1355	7.56	22.25	1.22	1897	1.24	.682	.488	.714	.700	1325
6	27.7	1545	9.02	26.10	1.5	2078	1.475	.712	.53	.744	.668	1390
7	31.	1795	10.24	30.60	1.76	2330	1.67	.695	.535	.772	.636	1480
8	34.5	2095	13.01	36.15	2.07	2588	2.12	.755	.611	.81	.587	1520
9	37.5	2295	13.50	40.6	2.32	2810	2.19	.712	.581	.818	.574	1610
10	40.6	2495	15.88	44.4	2.54	3045	2.57	.768	.63	.82	.572	1740
11	42.9	2655	17.00	50.0	2.86	3220	2.74	.77	.634	.825	.564	1815
12	46.9	2965	18.94	56.1	3.21	3515	3.04	.766	.646	.844	.536	1885
13	51.3	3225	20.63	63.2	3.62	3850	3.3	.763	.639	.838	.544	2095

7½ H.P. Wagner Induction Motor.

Volts Constant at 90. Speed 1761 R.P.M.

A.C. Ammeter 13457

A.C. Voltmeter 857

A.C. Wattmeter 775 May 21, 1900.

No.	Amp.	True Watts	Pull in pounds	Slip R.P.M.	Slip %	App. Watts	H.P.	True Eff.	App. Eff.	Power Factor	Induc. Factor.	Idle Watts
1	19.4	435	0	3.16	.17	1746	0	0	0	.2525	.9675	1689
2	23	1075	5.19	10.7	60	2065	.863	.599	.312	.5210	.8535	1716
3	25.6	1415	7.64	15.	.85	2304	1.26	.634	.325	6145	.7889	1820
4	30.9	2015	11.96	22.2	1.26	2780	1.79	.658	.493	7255	.6881	1910
5	34.9	2435	14.96	27	1.55	3140	2.46	.755	.585	7760	.6307	1978
6	38.	2685	16.77	30.9	1.75	3420	2.76	.767	.603	.7860	.6182	2115
7	42.6	3115	19.70	37.	2.10	3835	3.23	.775	.628	.8130	5821	2230
8	46.4	3465	22.21	41.6	2.36	4170	3.63	.781	.650	.8310	.5563	2320
9	52.	3905	25.25	49.2	2.60	4680	4.12	.788	.657	.8350	.5502	2573
10	59.	4325	28.25	56.6	3.21	5310	4.42	.763	.621	.8145	5800	3078
11	65.5	4725	31.37	62.5	3.55	5890	4.89	.772	.62	8030	.5960	3513
12	71.8	5075	33.13	69.	3.92	6460	5.28	.777	.611	.7865	.6175	3850
13	80.	5775	36.44	78.	4.42	7200	5.78	.746	.599	.8030	.5960	4285

7½ H.P. Wagner Induction Motor.

Volts Constant at 104. Speed 1745 R.P.M.

A.C. Ammeter 13457 + 13472.

A.C. Voltmeter 831

A.C. Wattmeter 775 May 10. 1900.

No	Amp	True Watts	Pull in Pounds	Slip R.P.M.	Slip %	App Watts	H.P.	True Eff.	App Eff.	Power Factor	Induc. Factor	Idle Watts
1	22.8	515	0	3	.172	2370	0	0	0	.2385	.971	2300
2	26.6	1355	5.63	10.35	.594	2770	.93	.512	.25	.489	.872	2415
3	28.	1635	7.76	12.5	.717	2910	1.28	.584	.328	.556	.831	2470
4	30.1	1915	9.88	14.63	.84	3115	1.63	.635	.39	.615	.788	2455
5	32.5	2185	12.19	17.65	1.01	3380	2.01	.688	.444	.647	.762	2575
6	35.	2525	14.65	20.7.	1.185	3640	2.41	.713	.494	.694	.719	2615
7	37.5	2815	16.63	23.6	1.35	3900	2.73	.724	.522	.722	.692	2700
8	40.2	3145	18.94	27.3	1.565	4180	3.10	.736	.553	.752	.659	2755
9	43.6	3515	21.69	30.	1.72	4540	3.54	.751	.581	.775	.632	2870
10	46.2	4015	28.25	35.3	2.02	4810	4.60	.855	.714	.835	.550	2645
11	49.2	4365	28.75	37.5	2.15	5120	4.67	.798	.681	.853	.522	2670
12	53.8	4755	31.45	41.65	2.39	5600	5.10	.801	.679	.85	.526	2945
13	57.	5175	34.30	44.4	2.54	5930	5.55	.800	.698	.873	.488	2895
14	60	5445	36.40	49.15	2.82	6250	5.88	.807	.703	.871	.491	3070

7½ H.P. Wagner Induction Motor.

Volts Constant at 120. Speed 1795

A.C. Ammeter 13472

A.C. Voltmeter 857

A.C. Wattmeter 775 May 23. 1900

No.	Amp	True Watts	Pull in Pounds	Slip R.P.M.	Slip %	App Watts	H.P.	True Eff.	App Eff.	Power Factor	Induc. Factor	Idle Watts
1	27.4	Cold 620	0	2.28	.0787	3285	0	0	0	.189	.982	3225
2	27.1	Hot. 525	0	2.	.111	3250	0	0	0	.162	.987	3210
3	28.	1055	4.44	5.88	.305	3360	.756	.535	.168	.314	.949	3190
4	30.3	1635	8.94	10.	.557	3635	1.52	.693	.312	.45	.893	3245
5	36.4	2775	17.44	18.75	1.044	4365	2.87	.772	.49	.636	.772	3370
6	42.	3585	23.54	25.	1.39	5040	3.97	.826	.588	.712	.701	3530
7	46.	4155	27.60	30.	1.67	5520	4.65	.835	.629	.754	.656	3620
8	50.	4745	31.62	33.3	1.86	6000	5.30	.834	.66	.791	.612	3670
9	55.3	5335	35.94	38.7	2.16	6640	6.00	.839	.674	.804	.594	3945
10	58.5	5715	38.32	40.	2.23	7015	6.40	.835	.68	.816	.577	4050
11	59.2	5815	38.98	41.1	2.29	7100	6.50	.834	.683	.82	.573	4070
12	63.2	6245	41.67	43.8	2.44	7580	6.95	.831	.684	.824	.566	4280

10 H.P. Wagner Induction Motor

Volts Constant at 208.
A.C. Ammeter 13472
A.C. Voltmeter 857
A.C. Wattmeter 775

May 18. St. Louis

No	Volts	Amp	Watts	Speed	Slip.	App Watts	H.P.	True Eff.	App Eff.	Power Factor	Induc Factor.	Idle watts.
1	207.8	11.7	525	1815		2430	0	0	0	.216	.976	2370
2	207.2	16.9	2585	1800		3500	2.5	.722	.533	.739	.673	2355
3	208.2	26.2	4555	1785		5460	5.	.819	.683	.835	.549	3000
4	207.8	37.9	6740	1760		7880	7.5	.830	.710	.855	.518	4080
5	206	55.	9125	1740		11320	10	.819	.659	.856	.517	5850
6	210.4	75.	13425	1685		15790	12.1	.672	.572	.851	.525	8290

Comparison of Instruments.

Readings taken during factory test of 10 H.P. Motor.

% LOAD	Voltmeters Wagner.	V of I	Ammeters Wagner	V of I	Wattmeters Wagner	V of I.	Speed R.P.M.
0	103.9	103.9	11.7	11.4	550	550	1815
25	103	103.6	16.2	16.5	2410	2610	1800
50	103.5	104.1	25.5	25.5	4770	4580	1785
75	103.25	103.9	35.5	37.	7150	6765	1760
100	102.5	103.	50.7	53.6	9350	9150	1740
120	104.75	105.2	77.	73.	13100	1345.	1685